

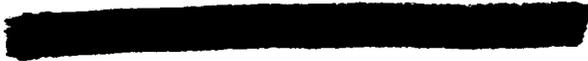
NASA Technical Paper 1364

A Critical Review of the Life
Sciences Project Management
at Ames Research Center
for the Spacelab Mission
Development Test III

Robert Helmreich, John Wilhelm,
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**A CRITICAL REVIEW OF THE LIFE SCIENCES PROJECT MANAGEMENT
AT AMES RESEARCH CENTER FOR THE SPACELAB MISSION**

DEVELOPMENT TEST III

**Robert Helmreich,* John Wilhelm,*
Trieve A. Tanner,** Joan E. Sieber,†
and
Susan Burgenbauch***

SUMMARY

Spacelab Mission Development Test III (SMD III) was the third in a series of ground-based studies designed to test logistics and management procedures for future life sciences space experiments, particularly Spacelab. This study was the first collaborative effort of the two NASA centers, Lyndon B. Johnson Space Center (JSC) and Ames Research Center (ARC) for such studies. ARC responsibilities were to propose, develop, integrate, and deliver a payload of life sciences experiments to JSC where a 7-day simulation was conducted. ARC developed documentation procedures, trained the crew on the experiments, and provided crew and management personnel as necessary for the successful completion of the project.

A management study was initiated by ARC to specify SMD III activities and problems. This report documents the problems encountered and provides conclusions and recommendations to project management for current and future ARC life sciences projects. An executive summary of the conclusions and recommendations is provided. The report also addresses broader issues relevant to the conduct of future scientific missions under the constraints imposed by the space environment. Many of the procedures recommended for consideration in the last section grow out of the experiences of SMD III; others are more general in scope and origin.

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I. INTRODUCTION

This report is the culmination of the SMD III Management Study, an investigation of the participation of Ames Research Center in Spacelab Mission Development Test III (SMD III). The study was designed to monitor preparatory activities and the development of policies for the test and to provide evaluations of those activities and policies in terms of their contributions to the successes and failures of the total project. The report is not designed to be a detailed chronicle of the day-to-day activities of either the development period or of the test itself, nor does it discuss individually all of the critical events of the project. The report is concerned with generic classes of critical events, policies, and problems that we have synthesized from the specifics of the project, although we discuss organizational and procedural methods that have been developed for handling generic problems.

In this part we give a brief summary of the SMD III project and the Ames project management organization. More detailed descriptions of the project and accounts of specific critical events and problems are given in other sources.

The goals of SMD III were to assess the feasibility of a dedicated life science space mission involving large numbers of on-board animals, to evaluate the ability of two distant NASA centers—Ames Research Center (ARC) and Johnson Spacecraft Center (JSC)—jointly to execute such a mission as essentially co-equal partners, and to evaluate the feasibility of a Science Operations Remote Center (SORC, a center for data presentation to project scientists). The project was of particular importance to the ARC Life Science Directorate as a test of its ability to support such a collaborative effort, especially its ability to staff the management organization necessary for the effort, and to enlist the necessary support from other ARC directorates.

SMD III was a ground-based, dedicated life science simulation of a Space Shuttle/Spacelab mission. The test itself was conducted at JSC from 17 May to 23 May, 1977, after a preparation and development period of about 1 year. The test was accomplished through the collaboration of ARC and JSC. The responsible directorates at the two centers were Life Sciences at ARC and Space and Life Sciences at JSC. They were supported by Research Support and Administration Directorates at ARC and the Flight Operations, Data Systems and Analysis, and Center Operations Directorates at JSC. The payload consisted of 15 animal experiments, 10 human experiments, 1 Earth observation experiment, and 15 operational test requirements (tests of hardware and procedures common to several experiments). The Ames experiment proposals, submitted in response to a memorandum from the deputy director of Life Sciences on 9 April 1976 (appendix A), were reviewed by a committee of peers. Proposals approved by the committee and by Ames management were submitted to a joint ARC-JSC committee for final selection.

The experimental package was selected to cover a broad range of life science research areas and to exercise as fully as possible the various critical elements of the mission; for example, hardware development, data handling, and crew training. As this was a development mission, not a preflight simulation, only partial attempts were made to impose zero-g constraints on the design of the hardware or on the experimental package. Rather, the thrust was toward including many experiments in enough different areas to stress the system to see where further development was needed. Major research areas that were represented included cardiovascular and pulmonary physiology; vestibular

functioning and motion sickness; and bone, muscle and general metabolism. The experimental subjects for the life science experiments were 4 monkeys, 97 rats, 6 mice, 6 frogs, several hundred fruit flies, and 3 crew members (for the human experiments). The on-board crew consisted of one mission specialist (a career science-astronaut from JSC) and two payload specialists (both physiologists, one from JSC, one from ARC). In addition, two back-up payload specialists were selected (a physiologist and a psychologist, both from ARC).

ARC responsibilities for the project were: (1) to propose experiments (both animal and human) for inclusion in the test; (2) to develop the hardware and integrate all animal experiment hardware into the mission equipment racks (actually the one JSC animal experiment was integrated at JSC); (3) to provide procedures documentation for ARC animal experiments; (4) to conduct crew task training on all ARC experiments, including training for the ARC animal experiments in the ARC portion of the test mock-up; (5) to select one payload specialist (in fact, ARC also selected the two back-up payload specialists); (6) to staff and operate the SORC; and (7) to supply appropriate project management personnel to accomplish the other ARC responsibilities (these personnel included two members for the inter-Center Mission Management Board, viz., the ARC project manager and science manager).

ARC participation in the project was formally initiated by the memorandum of 9 April 1976 from the deputy director of Life Science to selected Life Science staff members (Ap-A). The period from that time to roughly mid-October was primarily devoted to experiment selection and redesign, initiation of hardware design and development, crew selection, definition of experimental procedures documentation, planning of task training, and initial science briefings for the crew. Initiation of the Management Study began in early October and data collection began the week of 31 October. The period from late October 1976 until early February 1977 was primarily devoted to hardware development and integration, task training, and procedures documentation. For a few experiments, contrary to guidelines, extensive methods development and equipment redesign continued during this period.

On 14 February 1977 the ARC integrated hardware was shipped to JSC. From mid-February to 9 April hardware integration and continued task training occurred at JSC (primarily on JSC experiments and ARC human experiments). The period from 11 April to 29 April was scheduled for phase training (training in the mock-up following tentative mission timelines). However, the last week of phase training and all subsequent scheduled activities were delayed 1 week due to computer problems at JSC. A 2-day simulation of selected days from the 7-day test (integrated training) was conducted on 10 and 11 May. The 7-day test (which we will refer to as the simulation) began on 17 May. A more detailed chronology and classification of the critical time periods during the project is presented in section III.

The ARC project management organization is shown in figure 1. Although the project is shown to be the responsibility of the Biosystems Division, it should be noted that the Biomedical Research Division and the Man-Vehicle Systems Research Division (both also in Life Sciences) also contributed members to the management team. The day-to-day management of the project was actually vested in the project manager, who is represented by the Project Office box, and the roles of the Directorate and Biosystems Division management were chiefly those of financial support, consultation, and, when necessary, resolution (with JSC Directorate management) of intercenter policy discrepancies. The organizational diagram shows five categories of personnel under the Project Office: manager, secretary, contractor managers, crew and principal investigators. The dotted line between managers

and principal investigators represents limited authority (to be discussed later). Each of the three Life Sciences divisions also contributed principal investigators for the ARC experiments. Some of the management positions were filled by non-Life Science personnel or non-NASA (contractor or university grantee) personnel. Some personnel filled more than one role on the project, for example, management and principal investigator. The memorandum of 9 April of the Life Science Deputy Director alerted the directorate to the importance for total support from Life Science personnel, in addition to soliciting experiment proposals. The work time of some of the participants was totally committed to the project for its duration, especially in the case of personnel who filled multiple roles in the project.

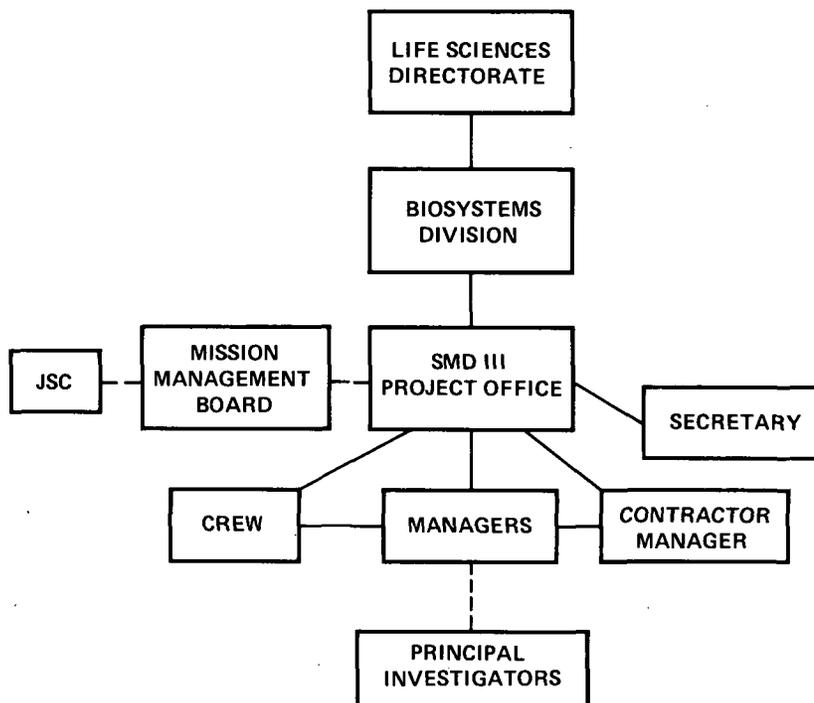


Figure 1. Spacelab Mission Development Test III: Ames Research Center Project Organization.

In the achievement of the goals presented above, the project was successful. The two Centers were able to collaborate in the execution of the mission; the crew was able to conduct the payload experiments within mission timelines; all but one of the experiments generated valid data; and the SORC was operated successfully in support of the ARC principal investigators. As suggested at the beginning of this introduction, the purpose of this report is to analyze the participation of the ARC team members in order to abstract those aspects of the participation that contributed to or detracted from the success of the project. Our goal is to provide conclusions and recommendations, supported by critical evaluation, that can be used by current and future project managers in planning, organizing, and managing similar projects. The recommendations presented here are relevant to life sciences as well as other scientific endeavors in future space missions.

In later sections of the report we discuss the importance of evaluating personal roles and actions during the performance of critical tasks by project personnel. We identify and evaluate the

role they played (or would play) and how they would play it again in contributing to the success or failure of SMD III or any similar project.

The remainder of the report is structured as follows. In Section II we develop a conceptual background that serves to organize later discussions of personnel roles and interactions. Section III describes the method of the management study and discusses some considerations about organizational research that influenced our approach. Section IV presents the data obtained from a written questionnaire used in surveying the project participants and in Section V we discuss major issues and recommendations based on information obtained from interviews supported by the questionnaire data. In Section VI, Future Research in Space, we discuss implications for future life science space research. The overall conclusions and recommendations are summarized in Section VII.

We wish to express our sincere appreciation to all the individuals who took time from their busy schedules to provide the information which makes up this report. We especially appreciate the thoughtful suggestions for improvement in the project which must, of necessity, be presented anonymously.

II. THEORETICAL BACKGROUND

The rationale for studying the organization and management of SMD III becomes clearer when we examine some characteristics of organizations and management. The description we offer of organizations and of management is incomplete and inelegant because no adequate theory or definition exists. As Drucker (ref. 1) explains, the organization is a fiction; it is the managers who make the decisions. Yet, managers respond to the nature of their task, their organization, and those who provide their resources and evaluate their products. Thus, management decisions are highly constrained and fraught with conflict. An organization is, in part, a network of information and work flow, and a healthy organization is one that continually seeks more effective and satisfying information and work flow networks. However, the members of organizations are dependent on the procedures, rules, or habits they have learned. Thus, there is a tendency to get "stuck" in a particular style, that is, persisting even when that turns out to be maladaptive in certain rules or habits. Getting "unstuck" is difficult since it requires willingness to seek information that may alter one's purposes, may indicate the weakness of the original approaches, and may arouse ambiguity and negative feelings in members of the organization (ref. 2). To engage in creative organizational change requires both a willingness to experience these kinds of stresses, and the availability of good information about what the organization is supposed to be doing, how roles are articulated, and how the organization is actually operating.

Information of this nature can have useful objective and subjective effects. Objectively, it can be used to create a more effective system of information flow through role clarification and reduction of role conflict, as we shall see presently. Subjectively, it creates rewards and motivation for individuals within the organization, resulting in their willingness to devote more energy to their work and to perform better. For example, Oldham (ref. 3) showed that motivation is increased substantially when managers define appropriate and specific roles for employees, and design feedback systems so that employees have objective information on how effectively they are performing. Also, in the course of providing a feedback system, managers gain an opportunity to perform an

even more effective motivating function: to recognize employees, personally and warmly, when they have done a job well (ref. 3).

The other function of information – to clarify and examine roles – is particularly important since role relationships in scientific research organizations turn out to be extremely complex, ambiguous, and fraught with conflict. The resulting distress and inability to work effectively can be extremely costly (refs. 4, 5). The examination and clarification of roles is a problem we have undertaken in this study; we hope this will provide information that will enable future management to improve information flow and role effectiveness. Since problems of role ambiguity and role conflict were reported throughout SMD III, we have drawn extensively on role theory to understand what was happening, and to find ways to improve role effectiveness in NASA scientific programs.

Role theory examines the forms of role conflict and ambiguity, their causes and consequences, and ways of reducing these undesirable situations. Role theory focuses on self-determination – the ability of the individual to learn both new roles and flexible integration of roles; the development of this ability is considered to be effective socialization. (In contrast, personality theory focuses on the individual's existing attributes and tends to regard these as fixed, however inadequate they may be). It was in keeping with the aims of this study to focus on a flexible model of social processes, such as role theory provides.

Typically, job training focuses on ability to fulfill a specific role, yet major problems within organizations have to do with whether persons are clear about which roles they should be fulfilling and whether they can handle conflicting roles. Accordingly, we assume the competence of individuals to do what they think they should be doing, and focus on role ambiguity and role conflict. *Role ambiguity* results from failure to communicate effectively to persons what they are to be doing. In SMD III, PI's and engineers tended to report a great deal of role ambiguity early in the study. *Role conflict*, on the other hand, has to do with incompatibility of roles. For example, managers were given major administrative responsibilities without the clerical support needed to fulfill those responsibilities, and thus had to take time from managerial work to carry out secretarial activities. Also, PI's who were also managers experienced periods when competing sets of responsibilities required that they work very long hours, and made difficult the effective discharge of both sets of duties.

Research has indicated antecedents and consequences of role conflict, relationships between type of position within the organization and types and amount of role conflict, and ways of reducing role conflict.

Causes

Role conflict is directly related to degree of innovation required, hence to fulfillment of scientific research responsibilities (ref. 6); to amount of coordination required across organizational boundaries (inside and outside of the organization) and hence to managerial roles (ref. 5); to supervision of personnel, hence to managerial roles (ref. 7); and to performance under the scrutiny of a powerful supervisor, hence usually to most members of middle management and lower echelons (ref. 8). Research projects using scientists as managers thus seem prime targets for role conflict and role ambiguity.

Consequences

Some consequences of role conflict are well-documented. They include tension, anxiety, dissatisfaction, physical illness (especially heart disease), tendency to leave the organization, lack of confidence in the organization, inability to influence decisionmaking, and unfavorable attitudes toward those who provide the role expectations (refs. 5, 9-11). All of these were either reported or observed during the course of SMD III. Although we cannot necessarily attribute cause for them to the project, these types of symptoms indicate role enactment problems.

Jobs and Role Conflict Patterns Engendered

Miles and Perreault (ref. 6) observed that scientist managers (that is, managers who also maintain research responsibilities, here called *principal investigator/manager*) experience the highest levels of role overload in scientific research programs and also experience high levels of role conflict. Typically, these are talented individuals who are chosen for their ability in their research specialty, their ability to lead research teams, and their ability to represent the organization to other sectors such as contractors, funding sources, and top management. Thus, they are exposed to multiple role requirements involving chronic stress, for which there seem to be substantial health and morale costs.

Another role that is perhaps less complex, but more unpleasant and stressful is that of the non-PI-manager, whose primary responsibility is to integrate activities strictly within the organization. While managers do not have as much role overload as PI/managers, they experience much more role conflict, exasperated by the fact that they work under closer scrutiny of relatively more powerful members of the organization (ref. 6).

Generally, the only persons who do not experience much role conflict are the highly buffered scientists – the PI's who do not have management responsibilities. However, these individuals who experience little role conflict also experience their roles as less powerful and less effective than those of the highly conflicted personnel (ref. 6).

Analysis of roles and role conflicts shows that, by the very nature of scientific organizations, certain roles are necessarily fraught with conflict. And when communication is poor, role ambiguity adds to the problem. However, steps can be taken to reduce the conflict as well as the ambiguity.

Person-role conflict can be managed effectively through careful selection and placement, so that personnel are given jobs that they feel like doing. SMD III has provided valuable information about the kinds of jobs that various individuals would prefer. Role conflict can be reduced by management through establishing more precise role definitions in the organization. Also, leadership training can sensitize people to when they are sending conflicting expectations, and teach them to acknowledge and at least attempt to soften the difficult conditions they create. What must also be developed is sensitivity to the difficulties of *spanning organizational boundaries and integrating organizational functions*, and to ways of reducing these difficulties.

Role overload can be alleviated by attempting to design jobs to even out pressures and responsibilities.

In the following parts of this report, role theory will be employed to examine the operation of SMD III and to explore ways in which scientific and managerial roles can be made more effective.

III. THE STUDY OF SMD III: PROCEDURAL ISSUES

The researcher must confront a number of serious methodological and ethical issues when studying an existing organization. Most of these issues center on the fact that the professional or vocational performance of individuals, rather than their isolated responses, are under examination. Because of the importance of these issues and their possible effect on the quality of obtained information, it is appropriate to consider them before describing the detailed procedures followed in the study.

Ethical Problems in the Study of Organizations

Typically, organizational research focuses on roles and processes in organizations as a whole rather than on the behavior of particular individuals within the organization. The purpose of the research is to achieve understanding (and perhaps improvement) of the organization. The decision to initiate research usually comes from a high-ranking member of the organization, who requests or directs other members of the group to participate and cooperate. Researchers then gather data using such techniques as observation, interviews, and examination of archival records. Thus, it is easy to overlook the rights of individuals within the organization and their personal concerns about the effect of the research on their status. However, the costs of neglecting these concerns are potentially high. They include: actually harming research participants through breach of privacy or confidentiality (with the possible consequence of gossip or unfavorable personnel action); upsetting participants; motivating participants to falsify the information they provide or to refuse to participate; creating a reservoir of ill-will within the organization; and creating strong resistance to any subsequent efforts to examine systematically and improve the organization.

In order to respect the rights and needs of participants in organizational research, the researcher needs a clear understanding both of the actual risks and benefits to all parties involved and of the kinds of grounded and ungrounded fears that members of the organization are likely to entertain. For example, it is entirely reasonable for members of an organization to wonder whether research findings could result in personnel actions such as raises, promotions, transfers, or firings, even if no such use is intended by either researchers or sponsoring management. It is the responsibility of the researcher to communicate with participants in a clear and credible way to prevent the generation of high levels of anxiety about consequences of the investigation.

Specific Goals and Approaches

The aim of this research was to study the management and accomplishment of SMD III in order to identify the organizational processes and problems that should be taken into account in the planning and conduct of future projects by NASA.

The aim was not to evaluate individuals who participated in SMD III. Indeed, the aim was not to evaluate SMD III per se, but rather to learn about generic processes and problems that can be expected to be a part of programmatic, mission-oriented scientific activities. The idiosyncrasies of individuals or activities are of interest only if they are likely to be found in one form or another in subsequent situations. Ideally, the use of this work will be in planning the effective development of future projects.

Several procedural guidelines were established with management and with individual participants before data collection was undertaken. One was that the research team would document the processes and problems encountered in SMD III without involving itself in the actual conduct of the project. One of us (Tanner) took on a management role after the research was begun. To avoid influence on the project, he did not examine any of the interview data or objective data until the project was completed. Members of the team would not attempt to influence the activities of the project in any way and would not serve as informal channels of communication among members of the organization. While individuals would be contacted regularly and their personal responses and perceptions recorded, the focus would be on the specification of generic issues. Data collected by the team on individuals would not be divulged to others.

Objective data were identified only by a code number and were maintained in computer resident files, making it impossible to identify respondents. Interview material and notes were returned to respondents after content analyses. Individual comments, where used, are presented without attribution or identification.

Several procedures were followed to obtain the informed consent and cooperation of project members. Participants were told by memorandum and in a briefing the purpose of the study, the procedures to be followed, and the potential value to NASA. The memorandum sent to project personnel is reproduced as appendix B.

Participants were individuals from ARC who were actively involved in SMD III or whose previous work in similar projects made them valuable commentators on the undertaking. Additional information was obtained from ARC management personnel whose operations were directly or indirectly affected by SMD III.

An unfortunate limitation of the study was the fact that research planning and data collection were not begun until the project was well under way. The first data were not obtained until the week beginning 31 October 1976, and the SMD project was formally initiated 9 April of the same year. Therefore, systematic contemporaneous data on initial organization, experiment selection, and early integration are lacking. However, retrospective reports of activities and problems were solicited and some first-hand information was supplied by one of the authors (Tanner) who was involved with the project in various capacities from the beginning.

Sources of Data

Two main sources of data were utilized – questionnaires and semistructured interviews. The basic questionnaire was given weekly. Respondents were asked for the allocation of time to various activities, completion of a checklist of problems encountered during the week, and specification of

groups interacted with as part of the project.¹ Space was also provided for comments on notable events. A final questionnaire, given 45 days after the simulation, asked for perceptions of the success and value of the project, both personally and for NASA, the importance of future simulations, and willingness to participate again. Both questionnaires are reproduced in appendix C.

Semistructured interviews were conducted to obtain information about problem areas encountered, reactions concerning organization and training, evaluation of personal roles and the project in general, and recommendations for the conduct of future missions and simulations. Most participants were interviewed at least twice, once at the beginning of the study and once after completion of the simulation. Several central personnel were interviewed a number of times while others, who were more peripherally involved, were seen only once. The number of interviews per person ranged from 1 to 17.

In all, 47 individuals provided data on their roles or perceptions of the project. A total of 118 interviews were conducted and 27 final questionnaires were obtained. Thirty-two participants began filling out the weekly questionnaire when the study began. Several individuals dropped off the project later, others were ill or on leave for one or more weeks, and some were unable to complete one or more forms because of travel or other commitments. A total of 786 weekly questionnaires were returned and coded, a weekly average of 82% return.

To provide some reduction in the mass of objective data collected and to examine group phenomena, mission participants were classified as belonging to one of five groups: (1) PI group, principal investigators for ARC experiments with no other specified roles in the project; (2) PI/manager group, ARC principal investigators with additional project management responsibilities; (3) manager group, ARC personnel with only management responsibilities for SMD III; (4) contractor/manager group, ARC contractors with management related roles in the project; and (5) crew group, ARC prime and backup crew members. In analyzing the data across time, individuals were classified according to the category filled during each time period.

One problem in the analysis was that three individuals changed role category during the course of the project. Another problem involved support personnel. Initially, due to the heavy demands of Life Sciences for engineering and shop support from other directorates, we felt it inappropriate to impose the systematic research program on personnel in these areas. Therefore, questionnaire data were not taken and these individuals are not included in our categorization of project personnel. Later, when project demands had eased, interviews were conducted with key personnel in the Research Support Directorate.

¹Because of time pressures in undertaking a study of an ongoing project, it was not possible to pilot-test the items and activity categories on the weekly questionnaire. During initial weeks of data collection we asked for criticisms and recommendations from participants with regard to the instrument. As a result of this feedback, an alternative classification of time allocation was developed and made optional for respondents. As it turned out, only two individuals, both contractors, used this form throughout. One manager used the alternative system for a few weeks, then returned to the original form. Data for these weeks are not included in the analysis. Because of the limited amount of data using this system, only data on total project time for these respondents are included in the discussion of activity breakdowns. Data on the discrepancy between time planned and time actually spent on project work were not included in the analyses because participants reported that this was extremely difficult to estimate. Most reported that they really had no idea at the beginning of a week how much time would be required each week for SMD and could not, therefore, estimate discrepancies.

Project Chronology

Thirty weeks of longitudinal questionnaire data were collected for the project management study. As mentioned previously, the study did not begin until about 6 months after the start of the project. To facilitate data analysis, these 30 weeks, which began on 31 October, were reduced to seven logically coherent time periods (fig. 2). Each period is labeled according to the dominant events during each interval. Obviously, a variety of activities was underway at both centers during each period.

A short description of the major events of the project during the management study will help to clarify our selection of these time periods. The top line of the major events section of figure 2 deals exclusively with training. Task training at ARC for the ARC and JSC crew was completed in weeks 1, 3, 6, and 7 of period 1. This training was conducted on the equipment in the laboratories of the individual PI's and included much definition of the tasks to be executed. Thus, period 1 is labeled "Task definition and training." Looking at period 2, "mock-up integration and training," we note that the mock-up facility was constructed and the hardware integrated into it, and that the equipment and animal holding facilities were tested. Week 10 had been scheduled as a training week at ARC; however, because the PI's equipment (which was taken from their laboratories where the initial task training had been conducted) was not yet completely integrated and there was no back-up equipment, it was cancelled. By weeks 13 and 14 task training was resumed using the equipment as integrated in the mock-up, and a pre-shipment review, double-checking the correct functioning of all integrated equipment and procedures, was completed. In the third period, the mock-up and all equipment to be shipped to JSC (the payload) were packed, shipped, and reassembled in the simulator at JSC. During the last 2 weeks of this period, two training weeks were scheduled but cancelled due to problems at ARC with the health of some experimental animals and at JSC due to hardware problems. The problem with animal health continued across several periods. Task training at JSC was the dominant activity in period 4, which ended with the science verification tests of all previously untested experiments as integrated in the simulator. Phase training occupied most of period 5. Note that phase training was interrupted because of data transmission problems for 1 week and then completed. This delay slipped the schedule for the simulation by 1 week. Had another week's delay occurred, the simulation would probably have been cancelled because of limitations on ARC resources, contracts, and animal considerations. But the project went smoothly from there on. Integrated training (a 2-day training in the complete, functioning simulator) was completed during period 6, and the 7-day simulation mission, SORC activities, and debriefing were completed by the end of period 7.

IV. RESULTS: TIME COMMITMENTS, PROBLEMS, AND INTERACTIONS

In this part we will describe the time allocation, major problems, and group interactions for the total group of participants, and examine these factors for the various subgroups of participants across time. These purely objective data provide a feeling for the effect of the project on its participants and for the kinds of hurdles encountered. They will be amplified by more qualitative material obtained from comments and interviews. Although the exact patterns of results are likely to differ from project to project, these data should have considerable utility in charting the differential demands of such endeavors across time.

Allocation of Project Time

Table 1 presents the average amount of time per week (in hours) spent on each activity by participants in each classification. Looking at the overall average, total time commitment averages 24.14 hr/week. Paperwork and meetings concerned with general administration of the project (including completion of reports, forms, requests, and briefings) took up the largest block of time, 6.38 hr/week. This was followed by clarification, follow-up, and monitoring (which includes seeking or providing information on experiments or programs, SORC or mission monitoring, and crew activities during the mission).² The total for this category was 5.75 hr/week. Overall, project administrative activities required more time than any other single activity.

TABLE 1. AMOUNT OF TIME PER WEEK SPENT ON EACH ACTIVITY
FOR EACH TYPE OF PARTICIPANTS IN SMD III

| Activity | PI only, N = 17 | PI/mgr, N = 4 | Manager, N = 8 | Con/mgr, N = 4 | Crew, N = 3 | p Value | Average for all groups |
|---|--------------------|------------------|-------------------|-------------------|----------------|---------|---------------------------|
| Total time, hr | 12.74 | 47.18 | 27.89 | 36.82 | 31.19 | 0.001 | 24.14 |
| Paperwork and gen. admin., hr | 1.93 | 17.95 | 10.55 | 8.41 | 2.32 | .001 | 6.38 |
| Program modification, hr | .39 | 1.42 | 1.99 | .18 | 1.08 | NS | .90 |
| Equipment design/redesign, hr | 4.25 | 5.99 | 3.23 | 11.54 | 4.07 | NS | 5.01 |
| Clarification, follow-up, and monitor, hr | 1.44 | 16.28 | 7.43 | 12.45 | 2.78 | .023 | 5.75 |
| Training, hr | 2.82 | 2.21 | 2.51 | .11 | 17.59 | .001 | 3.61 |
| Animal handling, hr | 1.54 | 2.87 | .36 | 0 | .18 | NS | 1.14 |
| Data collection and analysis, hr | .25 | 0 | 0 | 0 | .08 | NS | .12 |

²An unplanned outcome of the early classification system was that this category became something of a grab-bag in that it may refer to different activities for different people at different points during the project; for example, it records follow-up for the entire mission, crew performance during the mission, and SORC monitoring for PI's during the mission.

Equipment design/redesign (which includes actual work on the components of experiments or related equipment) followed with an average commitment of 5.01 hr/week. Training (including the planning and execution of training sessions and PI time spent with the crew) required an average of 3.61 hr/week. These major activities were followed by smaller commitments including animal handling (1.14 hr), program modification (0.90 hr), and data collection and analysis (0.12 hr).³ Uncategorized, miscellaneous activities accounted for another 0.85 hr/week.

Analysis of activities between groups and across time – In this section we will examine each activity to see how the groups of participants compare overall and across each time period. As previously noted, taking the project as a whole, “paperwork and general administration,” “clarification, follow-up and monitoring,” “equipment design/redesign,” and “training” occupied most of the total mission time. Within the total group of participants we have the five subgroups. The roles each group plays in the simulation are different, and these roles are reflected in their allocation of time to activities.

Total time – The groups show statistically significant differences for total time, paperwork, and general administration, clarification, follow-up and monitoring, and training. The other major activity, equipment design/redesign, showed so much variation by individual within the five groups that the overall differences between group means were not statistically significant. For total time (as measured by either the original or alternative time categories), PI/managers reported spending the most hours per week (47.18) working on SMD-related activities. As this is an average over 30

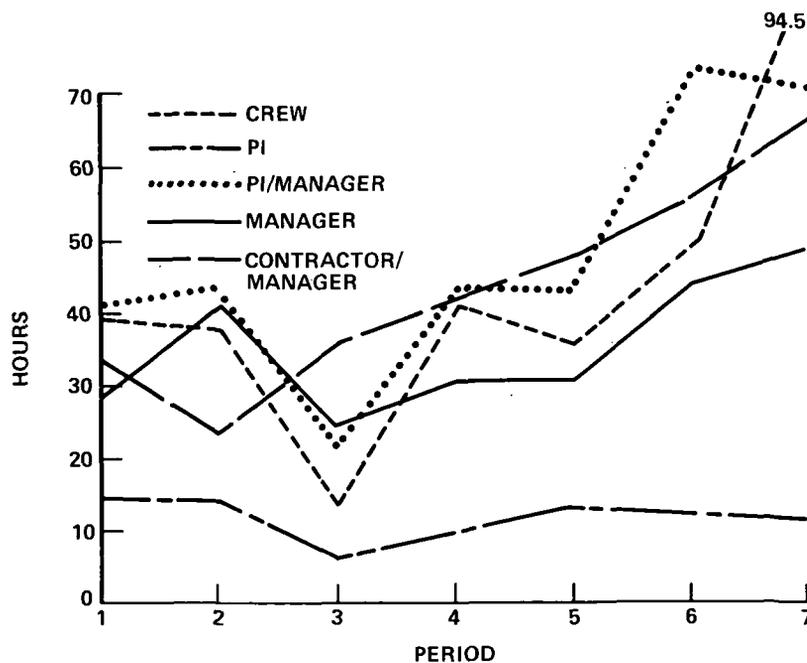


Figure 3.— Total time spent by each group for each time period.

³ Although not specified on the questionnaire, animal and data activities were listed so consistently in the “other activities” category that we pulled them from it and created two new activities. Obviously, we too have learned from our participation in the project.

weeks, the time they devoted to the project is truly remarkable. This group was followed by contractor/managers with 36.82 hr, crew with 31.19, managers with 27.89, and PI's with 12.74. The only group spending less than two-thirds of a normal 40-hour work week on SMD-related activities was the PI group. Figure 3 shows the average weekly time each group reported for all activities for each of the seven time periods. Immediately apparent is that the PI groups' participation differs from other groups throughout the mission: the PI's maintained a constant participation of about 12 hr/week across all time periods, while the other groups start out with about 35 hr participation, drop to about 25 hr during equipment integration at JSC, and rise again until, by the time of integrated training and simulation (periods 6 and 7), all four groups are averaging more than 40 hr/week.

Paperwork and general administration – PI/managers spent more time than other groups on paperwork and general administration, almost 18 hr/week. They were followed by managers (10.55 hr) and contractor/managers (8.41 hr). Thus, all the managerial groups, not surprisingly, reported the most paperwork and general administration time. Figure 4 plots the time spent per week in paperwork and administration for each time period by group.⁴ The PI/managers were devoting most time to paperwork and administration during the task definition and ARC task training period, during task training at JSC when animal health was in question (see subsection on problem areas, below), and during the simulation and debriefing period. Managers followed this pattern to a great extent, but showed a constant rather than increasing paperwork and administration load during the simulation. The crew's paperwork and administration time dropped slowly to nothing for the phase training period and then increased with the debriefings for the integrated training and simulation. The PI group remained fairly constant throughout the project.

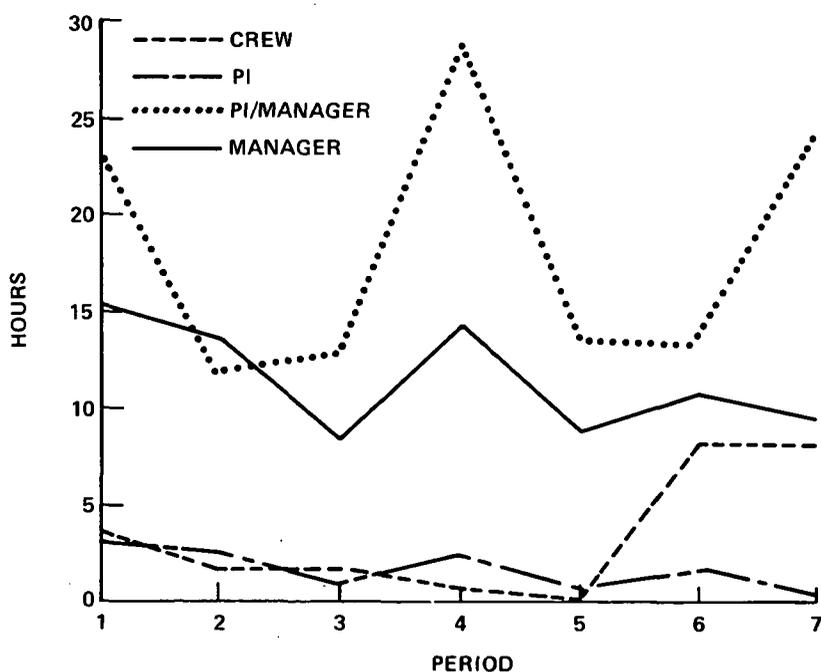


Figure 4.— Time spent on paperwork and general administration by each group for each time period.

⁴As noted earlier some of the contractor/managers used the alternative time categories. Because of the fragmented data resulting, this group is not considered in these breakdowns.

Program modification – Although program modification showed insignificant variation among the groups, several observations can be made about its pattern across time. Figure 5 shows that almost all program modification had ceased by the time of the actual simulation, but was preceded by a slight increase for PI/managers and PI's during integrated training. Across the first five periods, managers and PI's were fairly consistently involved in program modification activities, with the crew being quite involved during the first two periods and then dropping off. PI/managers fluctuate dramatically across periods.

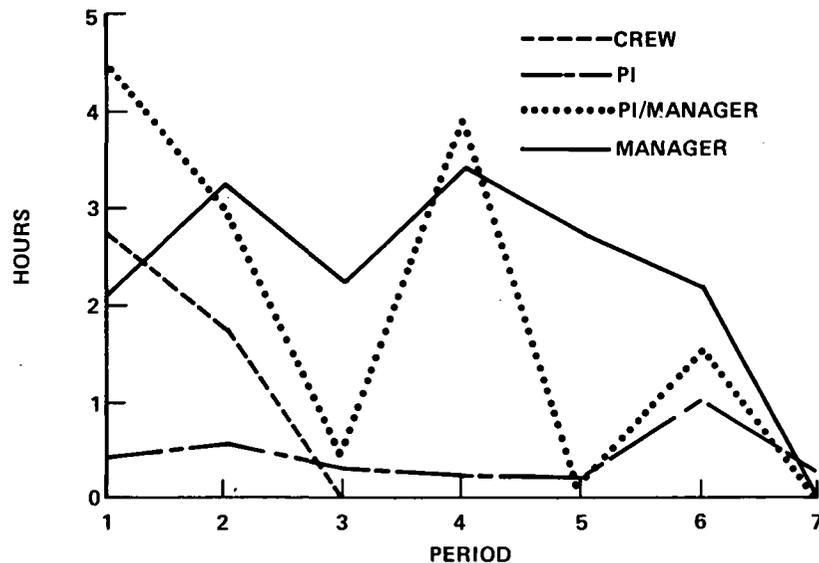


Figure 5.— Time spent on program modification by each group for each time period.

Equipment design/redesign – Equipment design/redesign work was done to a great extent by contractor/managers and PI and PI/manager groups. All the groups seemed to follow the same general trend, an increase between the first and second periods reflecting the mock-up integration activities, drops for periods 3 and 4, increases for 5 and 6 for final integration in the simulator at JSC, and a drop almost to nothing by period 7 (fig. 6).

Clarification, follow-up, and monitoring – The PI/managers, contractor/managers and managers showed the largest amount of time on clarification, follow-up and monitoring. As mentioned previously, this activity variable covers different activities at different times. For periods 1-5 it means clarification and follow-up, but for periods 6 and 7 it means mission monitoring (SORC) and crew participation in the simulation as well as clarification and follow-up. The increase in simulation-related activities can easily be seen in figure 7. Given the ambiguities in the meaning of this activity, we will not speculate on the specific pattern over the seven time periods for each group.

Training – The crew reported an average of 17.50 hr training per week with the next highest group, PI's, reporting only 2.82 hr. Training activities include training, being trained, and all training-related activities. All groups except contractor/managers were involved in the training of the crew. All groups showed peaks during periods 2, 5, and 6, and all showed a marked drop at period 3,

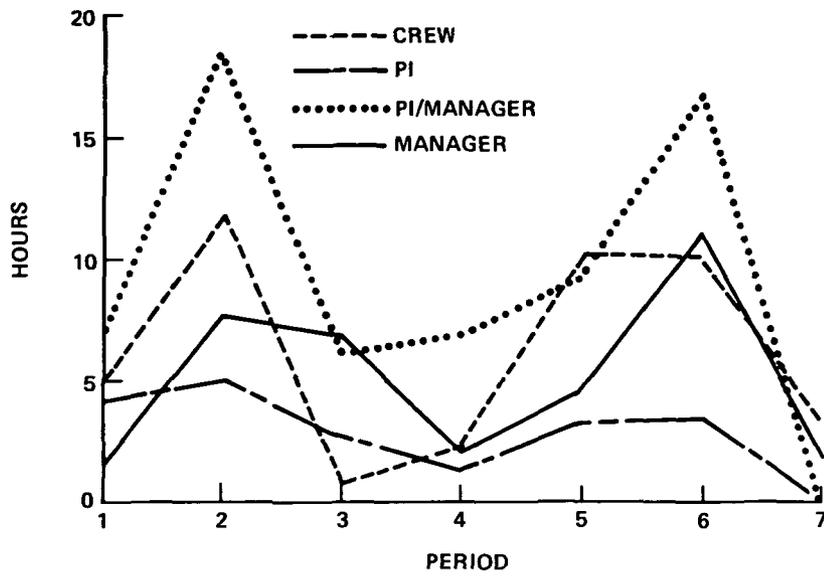


Figure 6.— Time spent on equipment by each group for each time period.

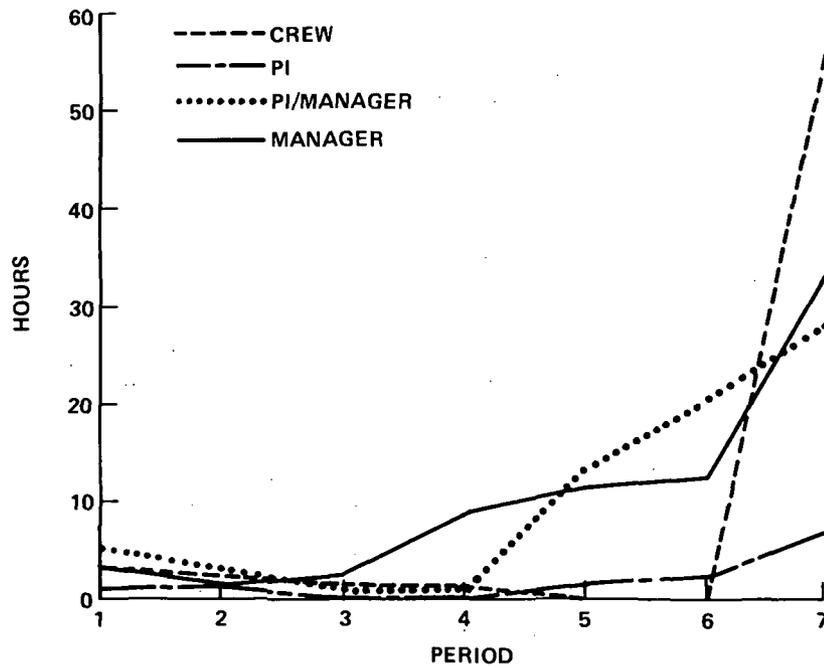


Figure 7.— Time spent on clarification, follow-up, and monitoring by each group for each time period.

equipment integration at JSC (fig. 8). These were training periods in which the crew was undergoing intense training on equipment integrated into the mock-up at Ames (period 2) and the simulator at JSC (periods 5 and 6). Training activities had ceased by the time of the simulation.

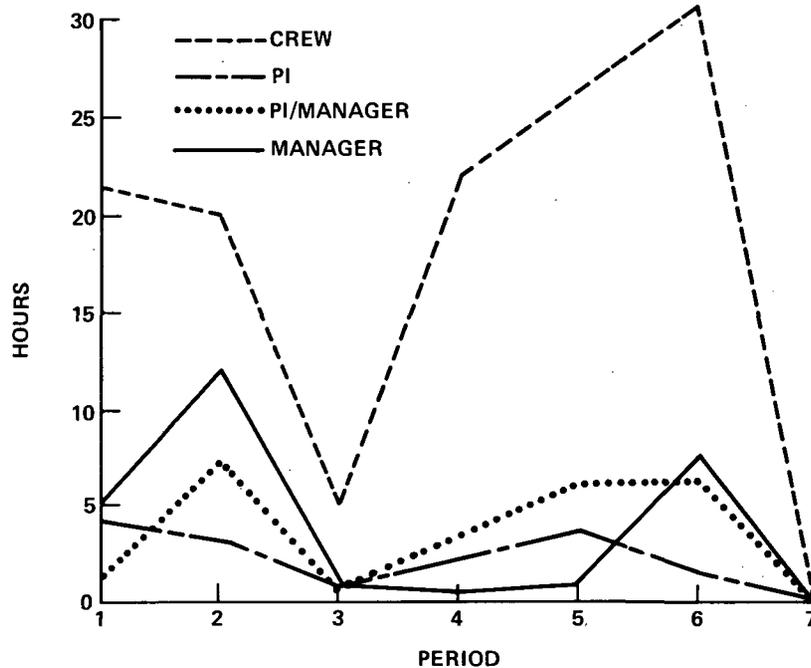


Figure 8.— Time spent on training by each group for each time period.

Animal handling – No significant differences were noted overall between the groups for animal handling. However, the only groups reporting noticeable amounts of time in this experiment-related activity were PI/managers and PI's. From figure 9 we note that the PI's show the most animal handling activities during the JSC task training period and phase training, while the PI/managers' work peaks during integrated training and the actual simulation. This activity was directly related to the animal experiments which were the responsibilities of PI and PI/manager groups. The first peak was related to task training and science verification tests, the last to phase and integrated training and preparation of animals for the simulation experiments.

Data collection and analysis – The PI group reported almost all of the data analysis activity. Figure 10 shows that this activity was concentrated early in the project with the design and testing of equipment and then during the actual simulation and debriefing for experimental results and SORC data monitoring activities.

Summary – The data show clearly that differences in time allocation reflect project roles, particularly in the relative weight of activities to total commitment. The differences in time requirements for the specific activities across time are very large. While the actual allocation of time in future projects will doubtless be very different, the *pattern* shown here may be a useful guideline for such undertakings.

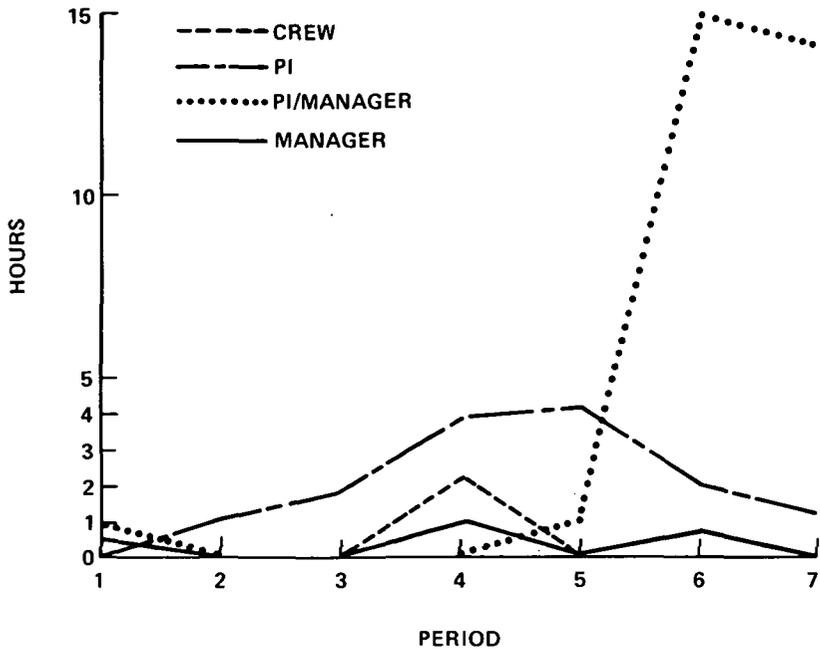


Figure 9.— Time spent on animal handling by each group for each time period.

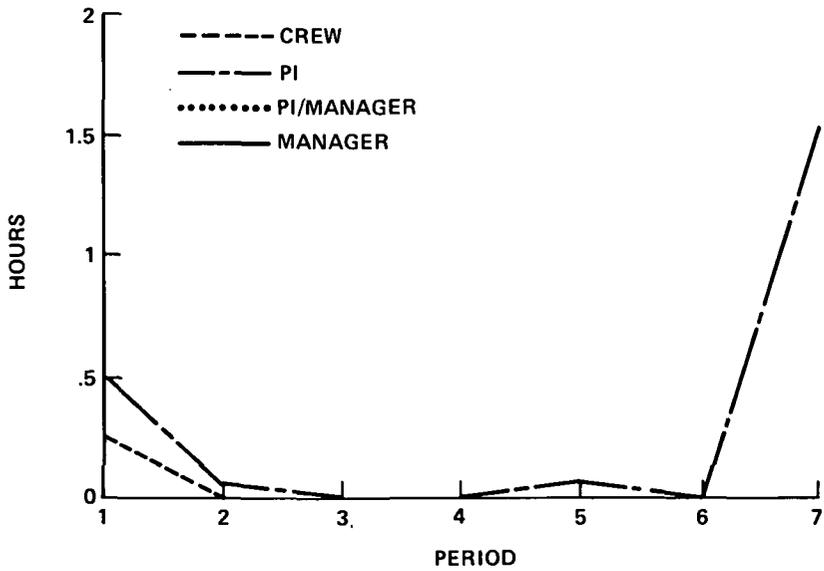


Figure 10.— Time spent on data collection and analysis by each group for each time period.

Problem Areas for the Project

In the problems section of the weekly questionnaire, respondents were asked to check which of 11 problem categories they had encountered in the week being reported. These areas were: (1) personnel – lack of or quality of personnel support; (2) equipment redesign problems; (3) problems caused by scheduling or execution of training; (4) problems in getting needed information; (5) problems in interfacing with other SMD experiments; (6) problems caused by interference of SMD with non-SMD work activities; (7) equipment integration problems; (8) timeline or scheduling problems; (9) problems in interfacing with JSC; (10) paperwork problems of any kind; and (11) other uncategorized problems.⁵ For each week respondents checked one or more problem areas or left them blank. Table 2 shows the percentages of each category of participant who checked the various problem categories in an average week. Examining the column giving the average for all groups, it can be seen that three problems were reported by at least 20% of all respondents in an average week. These were problems with equipment (design/redesign or integration), in interfacing with JSC, and in getting needed information.

**TABLE 2. PARTICIPANTS IN EACH GROUP REPORTING A PROBLEM
IN AN AREA ON AN AVERAGE WEEK**

| Problem area | PI's | PI/managers | Managers | Contractor/ managers | Crew | Average for all groups |
|---|------|-------------|----------|-------------------------|------|------------------------------|
| Personnel problems, % | 2 | 23 | 32 | 15 | 7 | 12 |
| Equipment problems, % | 16 | 48 | 34 | 22 | 32 | 25 |
| Training problems, % | 8 | 18 | 33 | 0 | 43 | 16 |
| Problems getting needed information, % | 8 | 35 | 41 | 16 | 34 | 20 |
| Problems interfacing with other SMD exp., % | 3 | 36 | 18 | 4 | 14 | 11 |
| Problems between SMD and non-SMD activities, % | 9 | 17 | 31 | 1 | 18 | 14 |
| Problems with timelines, % | 3 | 19 | 25 | 12 | 29 | 12 |
| Problems interfacing with JSC, % | 10 | 44 | 55 | 12 | 25 | 24 |
| Problems with paperwork, % | 8 | 31 | 27 | 10 | 12 | 15 |
| Number of problems per week | .77 | 3.01 | 3.33 | 1.09 | 2.37 | 1.67 |

⁵Since equipment design/redesign and integration problems showed such similarities, they were combined into an "equipment problem" category. If either original equipment problem was checked, we tallied a problem with equipment.

One major problem transcended the category system we had devised. This was the question of verifying animal health for the simulation. A committee set up to rule on questions of animal health did not establish guidelines until quite late in project development (February). At this time it was specified that monkeys had to be free of the "B virus" (Herpes Simiae, which has proved fatal in rare instances of transmission to humans). A number of the ARC primates were found to be possible latent carriers of the disease. The issue then became the establishment of standards to verify that animals for the simulation were free of the virus. The resolution of this question extended over a period of weeks. During its course it threatened timelines, training, integration of experiments, and relationships between the two Centers. To facilitate resolution of the problem, one PI assumed additional management responsibilities for the last half of the project. The management implications of this situation will be discussed in Section VII.

The equipment problem was ARC-specific and somewhat expected, given the scope of the engineering and integration task. The magnitude of the problem with interface between the two Centers suggests that project planners were correct in their perception that difficulties would arise in merging the activities of two geographically isolated groups with different histories and orientations. Getting needed information is not unrelated to the problem of inter-Center coordination. Because ARC Life Science had little experience in mounting this kind of project and because final integration was to take place in Houston, much of the needed information had to be ferreted out from various components at JSC. However, many of the problems in information exchange were internal to ARC, especially between various groups of participants, and will be discussed in greater detail in a later section. These major problem areas were followed by problems occurring with a moderate frequency: training (reported by 16% of respondents), paperwork (15%) and problems between SMD and non-SMD activities (14%). Personnel, interface of SMD experiments, and timeline problems were reported less frequently overall, but with at least 10% of the respondents reporting each of these problems in an average week.

Problem areas by type of participant and across time – An examination of the average number of problems per week reported by each group indicates that ARC managers were the group most plagued by problems of all kinds (averaging 3.33 problems per week). PI/managers followed with 3.01 problems. The contractor/managers reported considerably fewer problems (1.09) than the other managerial groups, but this is to be expected as they were assigned specifically to SMD III in a fairly limited role. They were not concerned with problems between SMD and non-SMD activities or with training. The role of management as a problem-solving component is highlighted by these data. The crew also reported a large number of problems, 2.37/week. The PI's were far behind the managerial groups and crew, reporting an average of only 0.77 problems per week. The specific problems which make up this overall total and their distribution throughout the mission will be discussed next.

Personnel problems – Problems with the quality or quantity of personnel support were not frequently reported in the simulation. The managerial groups reported almost all of these problems, especially the pure management group. Since the managerial staff had more groups reporting to them, it is reasonable that personnel quantity and quality should be primarily a management problem. Figure 11 shows the distribution of the personnel problem across the project. Pure managers reported personnel problems fairly consistently throughout the project. PI/managers, however, show an increased number of personnel problems during the latter phases of the project, especially during the integrated training.

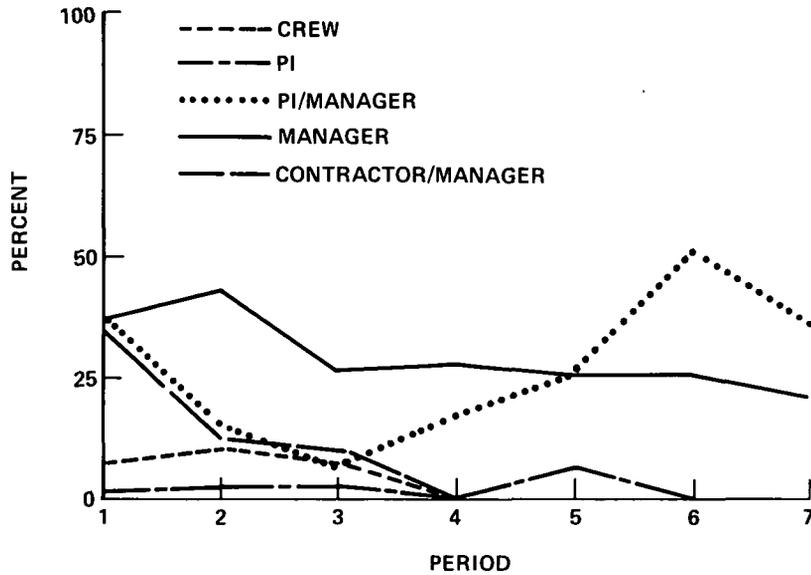


Figure 11.— Personnel problems reported by each group for each time period.

Equipment problems – Equipment problems were reported by all groups of participants. PI/managers reported this problem in almost half of their questionnaires. Equipment problems were the single most frequently reported problem for the contractor/managers and PI's for whom hardware development was a primary concern, and were a constant irritation for the other groups as well. Inspection of figure 12 reveals that all groups show a gradual decline in the number of equipment-related problems throughout the mission.

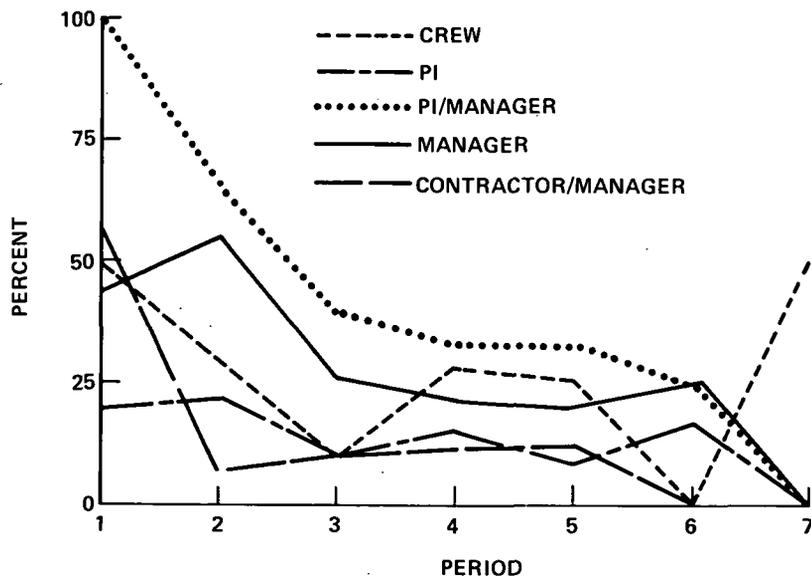


Figure 12.— Equipment problems reported by each group for each time period.

Training problems – Training problems were reported mainly by the manager group which was responsible for training coordination, and by the crew which was the focus of training activities. It is interesting that while the number of problems reported by managers stays fairly steady and even drops slightly as the mission moves toward the simulation (fig. 13), the crew reports an increase. This was probably due to the fact that some managers remained at ARC for the phase and integrated training. Specifically, the ARC training coordinator had essentially completed his task training responsibilities. The crew, which was at JSC for these periods, intensified their training commitments. The crew, in fact, reported training problems during the 7-day test. This was clarified in comments made by crew members. They reported problems during the test because they felt that training did not adequately prepare them for the workload. Even the two mission days selected for the integrated training were not representative of the more intense workload required during the actual simulation.

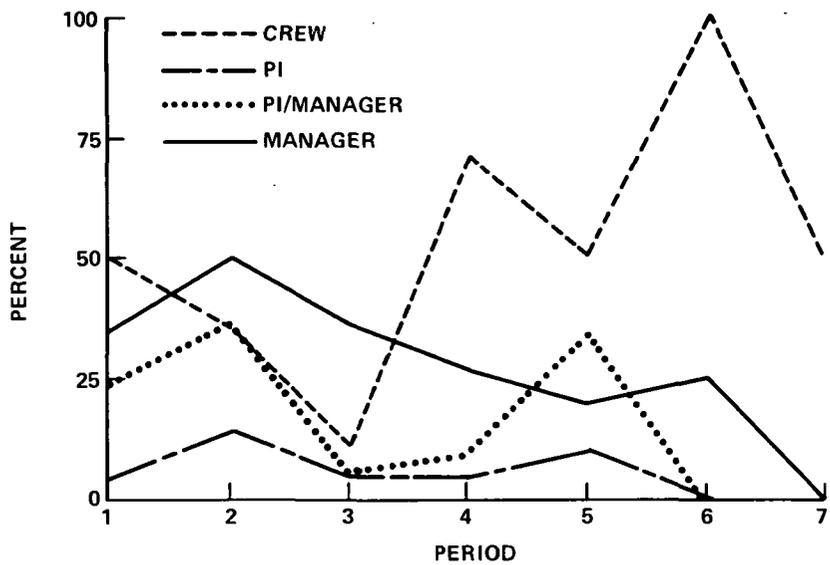


Figure 13.— Crew training problems reported by each group for each time period. (Contractors reported no crew training problems)

Problems getting needed information – Managers, PI/managers and crew reported considerable difficulty in getting the information they needed for various aspects of their work. As previously mentioned, much of this was inter-Center related. Figure 14 shows that problems in getting information declined for all groups during the ARC phases of the mission and increased dramatically during the JSC phases of the mission. The managers and PI/managers reported special communication problems with JSC during the integrated training and simulation periods, the periods of peak involvement with JSC.

Problems interfacing with other SMD experiments – While this was overall the least reported problem, it appears that it was a problem particular to PI/managers, and especially during the early parts of the mission when their experiments were being integrated into the mock-up simulator at ARC and during the actual simulation (fig. 15). The crew reported problems interfacing SMD experiments both during the integrated training period and during the simulation itself. The integrated training and the simulation itself were the periods when the crew had to work with all the experiments together following a timeline rather than on each experiment separately.

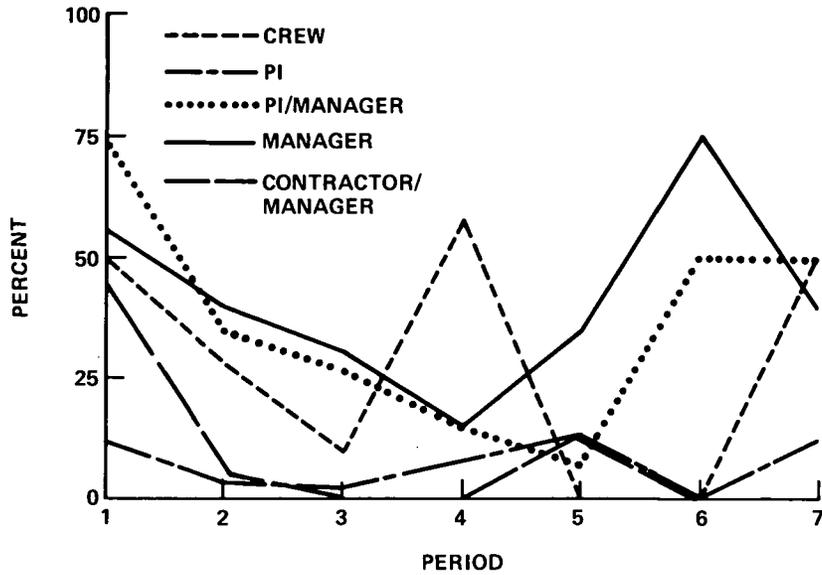


Figure 14.— Problems getting needed information reported by each group for each time period.

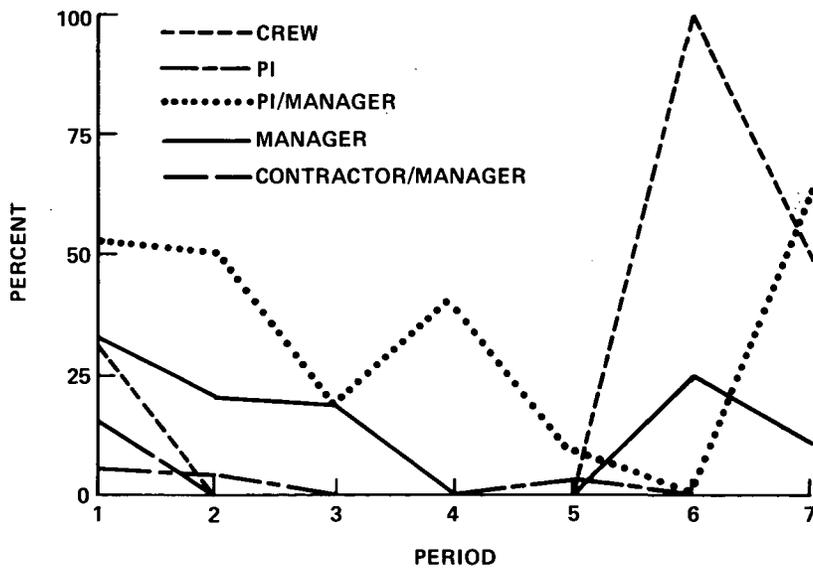


Figure 15.— Problems of interface with other SMD experiments reported by each group for each time period.

Problems between SMD and non-SMD activities — Managers reported most of the problems occurring between SMD and non-SMD activities. Given the fact that the mission was not one which freed the participants from other duties, it is surprising that it was not more of a problem than it was. Figure 16 shows this particular problem throughout the mission. Managers faced problems between SMD and non-SMD activities throughout the entire mission, but were especially affected during the latter part of the mission when their time commitment to the simulation was great.

PI/managers faced conflicts with non-SMD activities mainly during the mock-up integration and training period. The crew in particular felt the effect of SMD participation on their non-SMD activities during the task training at JSC and phase training periods when interviews revealed that the cancelled training periods disrupted their other activities.

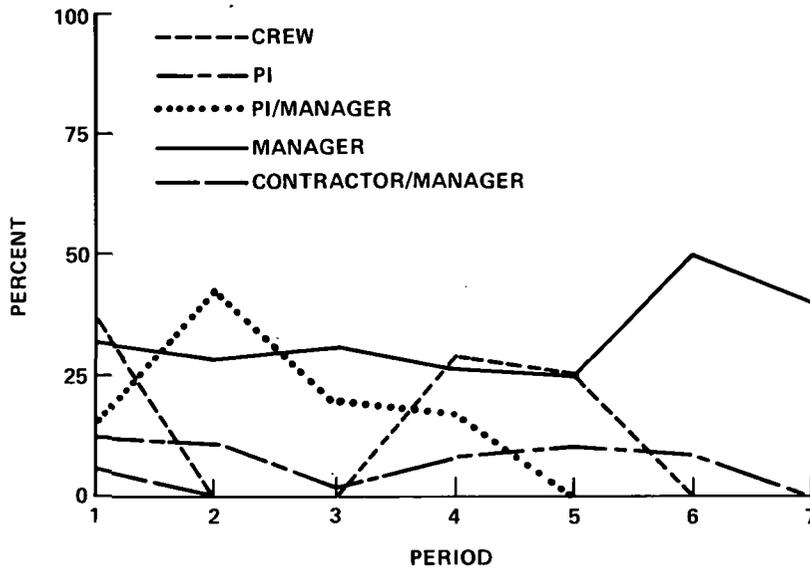


Figure 16.— Problems of interference of SMD with other (non-SMD) activities reported by each group for each time period.

Timeline problems – Problems with timelines or schedules were not frequently reported by any group, but crew, managers, and PI/managers reported them more often than others on the project. Figure 17 shows some interesting patterns across the project. Managers were most concerned with timelining and scheduling throughout the mission. However, the other groups show strikingly consistent peaks during the mock-up integration and training period, a major deadline for ARC, and during the task training period at JSC when the animal problem was being solved. PI/managers showed increasing timeline problems during the integrated training and during the simulation itself when the crew was reporting problems meeting the timelines. The role of management in scheduling is highlighted by these problems.

Problems interfacing with JSC – The problem most frequently cited by managers and the second most frequently cited problem of PI's and PI/managers was interface with JSC. Problems of communication were definitely increased by having management in two locations cooperating on the same project. Examining the distribution of this problem across time for each group (fig. 18) we see that different groups have problems at different times. Perhaps more striking is the fact that at no time during the mission was the interface problem insignificant. Although the problems of some groups peaked at certain periods during the mission, the JSC communication problem required constant attention. This points out the fact that continuous coordination between the two Centers was required throughout the mission. More than half of the managers reported this problem. The problem peaked during integrated training and the 2-day simulation. It should be noted that this was the period immediately before the simulation was scheduled to take place and that there were real

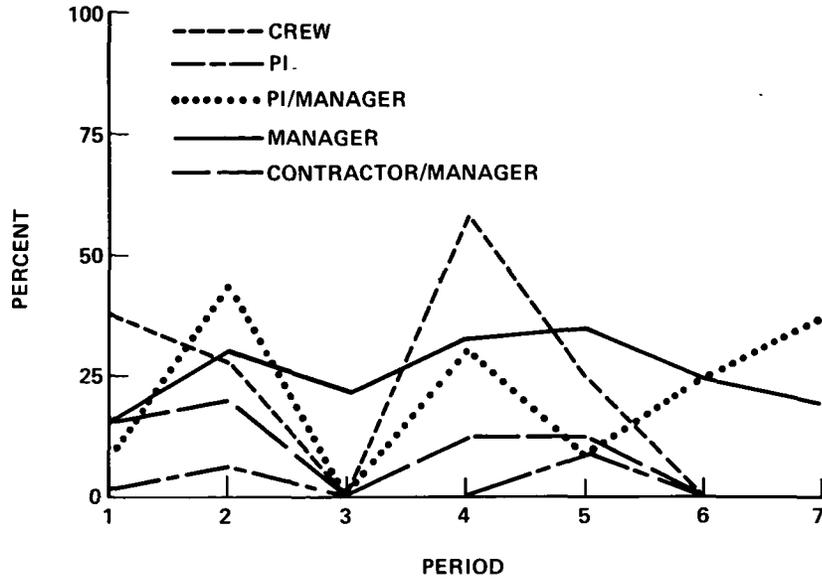


Figure 17— Problems related to time lines reported by each group for each time period.

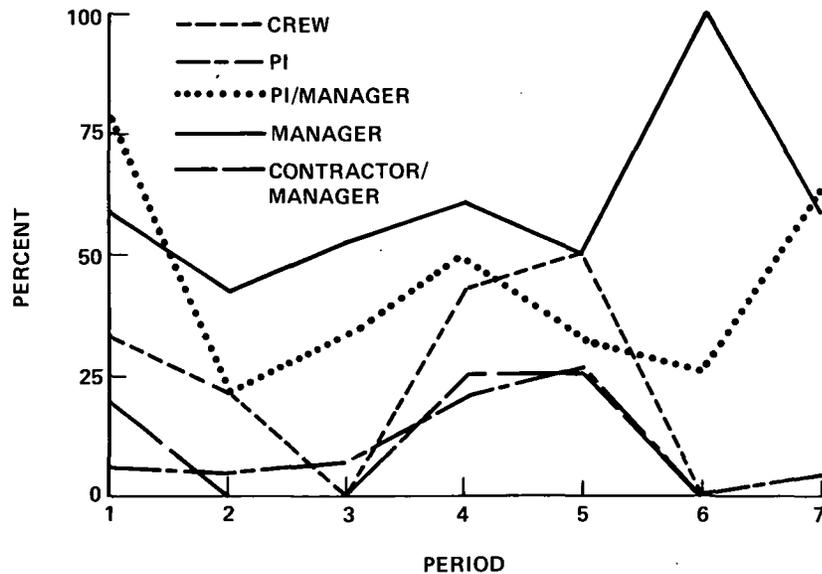


Figure 18.— Problems of interface with JSC reported by each group for each time period.

prospects during this period that the simulation might not happen at all because ARC resources could not tolerate an extended delay. Animal problems plagued the managers during this period also. PI/managers reported more problems very early in the mission, during task training at JSC and during the actual simulation. The problems of the crew, PI, and contractor/manager groups occurred mainly during task and phase training at JSC. During the last phases of the project, the participation of all groups in the study peaked and the communication procedures were being established for the simulation.

Problems with paperwork – Managers and PI/managers reported the most paperwork problems, as well as the most paperwork activity. These groups reported paperwork problems at a low, fairly constant level throughout the project (fig. 19), with the exception of the equipment integration phase at JSC when their problems decreased. This was probably due to the fact that they had more time available for their paperwork activities, having just met a major deadline in getting the equipment shipped to JSC.

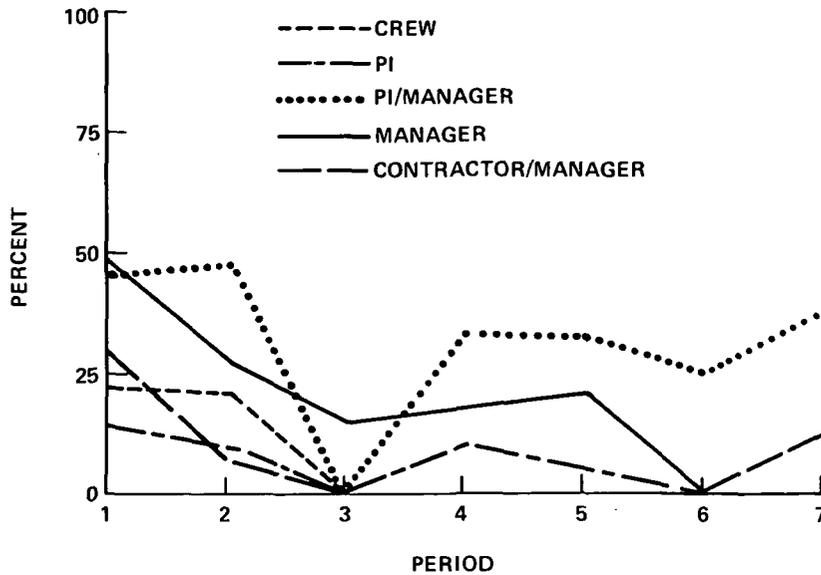


Figure 19.— Paperwork problems reported by each group for each time period.

Group Interaction for the Entire Project

From the list of people with whom participants had had the most important interactions in the past week regarding SMD, we defined eight groups according to the function of the person interacted with. For example, if the participant interacted with a PI/manager in reference to a management problem, we coded the interaction as one with a “manager.” If the interaction was with the same man regarding his experiment, we coded the interaction as being with a PI. Some groups with which the participants interacted were not in our management study; for example: shop, engineer (code R) and JSC crew. As these groups were an integral part of the overall simulation, we considered them as a functional group. The percentages of all participants reporting an important interaction with each of the resulting groups for an average week are reported in table 3.

For participants in the weekly questionnaires, most communication was channeled to ARC managers and contractors, followed by JSC personnel other than crew (this includes JSC management). Groups receiving intermediate amounts of communication were ARC engineers and PI’s, and ARC and JSC crew. ARC shop received the least amount of communication of all groups.

TABLE 3. SIGNIFICANT INTERACTIONS BETWEEN ARC AND OTHER GROUPS

| ARC group | Functional groups | | | | | | | |
|--------------------------------------|-------------------|---------|----------|----------|-----------|----------|-----------|----------|
| | ARC PI's | ARC mgr | ARC engr | ARC crew | ARC contr | JSC crew | JSC other | ARC shop |
| PI's interacting with | 11 ^a | 59 | 33 | 21 | 28 | 21 | 21 | 9 |
| PI/managers interacting with | 10 | 87 | 16 | 19 | 56 | 19 | 44 | 10 |
| Managers interacting with | 27 | 87 | 19 | 19 | 49 | 8 | 34 | 8 |
| Contractor/managers interacting with | 27 | 88 | 18 | 0 | 61 | 4 | 27 | 6 |
| Crew interacting with | 55 | 40 | 18 | 33 | 8 | 50 | 33 | 3 |
| All groups together interacting with | 20 | 71 | 25 | 19 | 38 | 18 | 29 | 8 |

^aNumbers represent the percent of each ARC group which reported a significant interaction with each of the functional groups in an average week.

Looking at the groups separately, some interesting patterns emerge. Perhaps most interesting is that all three groups with managerial roles have such strikingly similar communication patterns. All three groups were characterized by frequent communication with other ARC managers, ARC contractors, and with JSC personnel other than crew, by a moderate amount of communication with ARC PI's and little communication with the crew. In contrast, the PI's, in addition to their communications with managers, had more frequent contact with engineers than any other group, but little communication with other PI's. PI's interacted somewhat more with the crew than managers. The crew had less frequent communications with the managers than any other group. Their important communications were with PI's and the JSC crew. They were notably lower than the other groups in their frequency of communication with contractors.

These data have not been analyzed by each time period because the number of data points generated by this small sample would have been enormous and would probably add little new information to that already discussed in the activities section.

Results of the Final Questionnaire

How successful was the overall project in the eyes of its participants? The post-mission questionnaire designed to assess this and related questions was administered a month and a half after

SMD III was completed. The questions themselves and the results are shown in table 4. The success and value of SMD III were seen as higher for ARC than for the individuals personally or for NASA as a whole, but all participants saw the simulation as successful and valuable. The average scores on all aspects of the success and value of SMD III were between 4 and 5 on a scale with 5 as the maximum score. There were no significant differences between the five previously described types of participants in their estimation of the value and success of the mission.

TABLE 4. SMD III PROJECT MANAGEMENT SURVEY POST-MISSION QUESTIONNAIRE^a

| Question | Average | Standard deviation | Range |
|---|---------|--------------------|-------|
| What is your evaluation of the overall success of SMD III in terms of: your own role? | 4.17 | 0.76 | 3-5 |
| ... ARC? | 4.79 | .41 | 4-5 |
| ... NASA? | 4.21 | .62 | 2-5 |
| How valuable was the exercise for: you? | 4.21 | 1.01 | 2-5 |
| ... ARC? | 4.72 | .53 | 3-5 |
| ... NASA? | 4.21 | .81 | 2-5 |
| How useful would be another simulation (or development) of the first dedicated life science spacelab mission? | 4.04 | 1.14 | 2-5 |
| If Ames is involved in another simulation, how interested would you be in participating? | 4.00 | 1.00 | 1-5 |

^aEach question was answered on a 5-point scale which ranges from 1, "not at all," to 5, "very."

The question about the usefulness of another simulation (or development) of the first dedicated life science Spacelab mission elicited the largest variance in responses, but the average (4.04) still indicates that most participants think another simulation would be useful. Would the same participants be interested in participating in another situation? The response was a qualified "yes." Seventy-eight percent checked a 4 or a 5, 15% checked a 3, and 8% checked a 1 or a 2. Thus, most participants would be very interested in participating in another SMD, but a few, for whatever reason, would not. These individuals also doubted the utility of another SMD. Interviews clarified the fact that SMD III satisfied the need for a development test as a partial simulation while demonstrating the importance of a full mission simulation.

A striking point in these data is the broad acceptance of the philosophy of projects such as this for a research organization like Ames. It is clear that these scientific personnel are interested and enthusiastic about such team efforts.

One question which was asked but not tabled requested respondents to choose which roles they would like to fill if involved in another simulation. The options were crew, PI, manager, and engineer. Respondents were free to circle more than one category. When we examined these results, we found that most of the PI's wanted to be PI's in another mission, PI's with management responsibilities wanted to be crew/PI/managers, contractor/managers wanted to continue in that role, and crew wanted to remain crew. Most of the participants were satisfied with present roles and desired to continue in them, perhaps adding an additional role in some cases.

V. MAJOR ISSUES AND RECOMMENDATIONS

In this section we will draw heavily on material from the 118 interviews. These interviews, which were informal and open-ended, focused on the effect of events and policies on the respondent's role in the project and the nature of responses to problems and issues. The level of cooperation was remarkably high. Respondents were not only candid in describing their perceptions of the project but thoughtful in offering recommendations that might improve the operation.

Effect on Other ARC Activities

Both interview and questionnaire data indicate that SMD III had considerable effect on the normal pursuits of individual participants and of three of the four Divisions. For the Life Sciences Directorate as an entity, this was reflected in the diversion of funds and manpower from usual scientific activities to a collaborative project not designed to generate empirical, scientific data in the usual sense. It meant shifting the activities of enough personnel to influence completion of planned programs under several RTOP's. For many individuals, it meant the postponement or serious reduction of ongoing research for a period of up to a year. The latter effect on research was caused not only by the project's time demands on participating scientists, but also because research equipment employed in ongoing research was tied up by the project.

Reactions to the project varied. Some showed early and sustained enthusiasm, others early doubts followed by strong commitment, still others continued questioning the value of the enterprise. In general, initial reactions were lukewarm. The consensus by the end of the project, however, was that the project had great value for ARC and was an important learning experience for scientists unaccustomed to collaborative, scientific projects. Most initial resistance and reservations appear to have come from the fact that participants did not perceive the importance of the simulation for Ames, namely, that it should demonstrate both the capability of ARC in supporting an integrated in-flight research program and the feasibility of conducting basic life science research under the constraints of space. Principal investigators in particular tended to have less enthusiasm initially because they perceived the project as requiring a large commitment of time without any payoff in the form of publishable data.

The individuals who most consistently reported interference with other nonproject activities as a problem were PI/managers. This group, it will be recalled, averaged over 46 hr. a week on the project. For them, SMD III was more than a full-time job, precluding virtually all other activities.

It is possible that dissatisfaction with the interference caused by the project might have been reduced had the goals for ARC and the possible benefits for individual scientists, especially PIs, been laid out more explicitly prior to the project. It appears, from the attitudes of participants, that the utility and personal benefits are now widely understood and that future projects of a similar nature would have more complete support from the beginning. Nevertheless, the extent of misperceptions and misgivings encountered initially in SMD III suggests that prior to the initiation of future simulations or missions every effort should be made by management to provide explicit information on Center and Directorate goals and the expected level of commitment from participants. Long-term priorities should be spelled out and prospective participants should be assured that their normal job will not be jeopardized if they choose to participate in the project.

Collaboration Between ARC and JSC

In general, many participants expressed satisfaction and some surprise at the high quality of the collaboration achieved between ARC and JSC. As we have noted, a significant proportion of the problems encountered related to interface with JSC, but these figures can be misleading in that many of them undoubtedly would have appeared as internal problems at ARC had the project been conducted entirely at ARC. The most frequently cited problems relating to inter-center cooperation concerned getting needed information. Participants at ARC felt that JSC as the site of the project could have been more efficient in providing information on earlier simulations, current mission guidelines, equipment integration requirements, and status of experimental animals. We suggest that a central project office could have alleviated many of these problems.

Other issues concerned difficulties in working with engineering personnel at JSC over the telephone (although some PI's reported complete satisfaction with such collaboration), and the fact that several contractors at JSC were not set up to deal with particular requirements of ARC experiments. For better engineering coordination between Centers, early efforts should be made to establish a team relationship between the engineers at one Center and engineers at the other, and between individual PI's and the engineer responsible for their equipment. A major source of concern was the maintenance of experimental animals at JSC prior to the simulation. If one Center is responsible for delivering the animal payload to the other, it should review the animal health and maintenance procedures of the recipient Center in order to reduce concerns of one Center with the procedures of the other. Other interface issues will be discussed with regard to the Science Operations Remote Center.

The Science Operations Remote Center (SORC)

The justification for a SORC is the need for an operation center close to the concentration of facilities and PI's required for mission support. Specifically, ARC has the capability for animal research and support. Because of this capability, ARC is the logical location for the specialized

hardware and staff required for ground control of animal studies, including, if required, yoked control groups for flight experiments. Therefore, ARC also appears to be the logical receiving point for flight data on such studies.

The consensus of project personnel was that the concept of a SORC was verified and that such a center can be usefully employed for data presentation and communications in space missions. Despite overall favorability, a number of concerns and problems were cited by ARC personnel. From the PI's point of view, the most serious were restrictions on communications with crew members responsible for particular experiments. Most felt that the slow-scan TV was of restricted utility. Management personnel also expressed concern that rules for communication with the Payload Operations Control Center (POCC) and the crew were not clearly defined (one referred to them as "whimsical") and were more restrictive than necessary. In at least one instance, an important message to the crew regarding experimental procedures was delayed and incorrectly relayed.

A number of managers and PI's expressed the feeling that the presence of PI's in the SORC (or POCC) is essential during the conduct of experiments.

The experiences gained during SMD III suggest that the value of a SORC in terms of scientific productivity would be enhanced by a clearer and more liberal policy for POCC-SORC and SORC-Crew communications. The following procedures would appear to be most desirable:

1. Provide SORC management with access to all POCC communications. A video link between POCC and SORC would add to the management efficiency of the SORC. This concept was explored during Project Tektite 2 and proved highly effective (refs. 12, 13).
2. Place as few restrictions in possible on PI-crew communications. A separate voice channel for each crew member would be highly desirable.
3. A hard copy printer in Spacelab would permit transmission of important information to crew members at times when voice communications are overloaded or not feasible. It would also facilitate the transfer of technical instruction to the crew. In Skylab, such a facility was apparently of considerable value.

The issue of communication between PI and crew will be discussed further in section VI.

The presence of at least one dissenting vote to conclusions about the value of the SORC should be noted. One participant felt that the critical issue was free communication access to the crew and the presence of the PI to evaluate procedures. This respondent felt that the communications could be as easily and perhaps more economically effected from a single mission control. Perhaps future decisions regarding SORC could more appropriately be made by a cost-effectiveness evaluation of SORC (ARC)-POCC (JSC) vs POCC-SORC (JSC).

Principal Investigators

As we have noted, most of the principal investigators felt that SMD III was an important learning experience in the conduct of project research under conditions such as those in space.

Several did, however, express concern over the loss of productive research time (a problem they felt would be reduced in a real mission by the value of research conducted, but not eliminated because of the greater time demands of this type of research). Several voiced concern that PI's from universities might have great difficulty in adapting to the time demands and procedural constraints imposed by the project environment. PI's (especially non-NASA PI's) must be made aware of realistic time requirements, autonomy constraints, and procedural requirements. They can then appraise the effect of running a space flight experiment on their time and resources before committing themselves to such a project.

In one instance a university PI who did not have an in-house collaborator or technical monitor involved in SMD III experienced difficulty obtaining information and keeping track of the integration of the experiment. It has been suggested that in-house, NASA scientists should normally serve on experiment teams and fill the role of coordinator and liaison. Several also felt that equipment to be flown should be duplicated in the PI's labs (or perhaps in the integration facility) to facilitate other research and experiment training.

Most of the difficulties experienced by PI's concerned obtaining information, defining roles in decision making, and establishing effective communications with other project personnel. Several expressed a strong need for a handbook specifying the capabilities and limitations of Spacelab and the operational organization of the mission. Related to this, it was consistently felt that not enough feedback was obtained from management and that PI's were often unaware of modifications in procedures which influenced the conduct of their experiments. PI's and their liaisons should be consistently informed by management, especially about any modifications in procedures which may influence the conduct of their experiment. Some managers, however, felt that PI's often did not give proper attention to information that was presented to them. Part of the problem may be the signal-to-noise ratio. Some PI's suggested that they received so much irrelevant (for them) information that important information often may have been overlooked. Because of this problem, we suggest that the flow of paperwork be filtered so that only relevant information is sent to the appropriate persons. Increased clerical support would aid greatly in this task.

PI's expressed a need for clear lines of authority with regard to decisions about experiments. They particularly wanted a role in the assignment of crew members to particular experiments. Considerable emphasis was placed on the importance of establishing early rapport with crew members and working together on experimental procedures. As we have noted above, the need for extensive communication with the crew during conduct of the experiment came up repeatedly.

An important reflection after the simulation was that the most important and effective research in this environment could be conducted by a consortium of scientists with related interests and experiments.

All of the comments raised by PI's here and with regard to the SORC appear to be thoughtful and worthy of serious consideration by management. Suggestions regarding their implementation have been incorporated in section VI.

Crew

Information on issues regarding crew function comes from ARC personnel serving in prime or back-up crew roles and from other project personnel. The precise status of crew vis a vis principal investigators with regard to their role in the execution of experiments was not clearly defined and was a source of some confusion and misunderstandings. While it is obvious that crew members will carry out experimental procedures during flight, the extent of their autonomy was unspecified with regard to the actual execution of the study, data collection, collaboration prior to the mission, and consultation during the flight.

The issue of back-up training for crew members was not fully resolved. Initially, a back-up for both payload specialists but not for the mission specialist was planned. The intention of the ARC management was to train the back-ups to the same level of competence as the prime crew. This was feasible in task training but was not possible during phase and integrated training because the crew trained as a three-person team during these later stages.

We will not take a position on the need for back-ups, but do feel strongly that the role of back-up crew members and the extent of their commitments for training should be made clear and communicated to PI's and crew candidates at the outset.

The consensus is that the scientific role of each member of the crew (mission and payload specialist) must be defined and the lines of authority and communication between the crew and science management and crew and PI's set forth. These should be made explicit to all personnel at the inception of the project and should include clarification of such issues as whether the mission specialist or the particular payload specialist (or both) should be responsible for evaluating the adequacy of preparations for particular experiments. Suggestions concerning appropriate crew roles in the broader context of future Spacelab missions and simulations are presented in section VII.

Management

Members of all segments of SMD III felt that an effective management team developed during the course of the project. Evaluation of this capability was seen as critical by many since very little experience with this type of program management was available in the scientific areas relevant to SMD III. Several respondents stressed the point that the management capability developed during SMD III should be used as a basic resource for future programs.

Most of the comments made by management and other personnel were aimed at improving on this satisfactory performance in future projects. Some are highly specific, others more general. We have previously mentioned the perception of some PI's that they were not sufficiently included in the network of communications, particularly regarding decisions concerning their own experiments. Conversely, it was suggested that there was insufficient monitoring by management of the progress of PI's experiments. Project organization did not give management line authority over PI's during the course of the mission development and simulation. This was not a serious problem because of the cooperation of all concerned. In section VI, however, we will discuss the advantages of a clearer structure with regard to PI's.

It was widely agreed that some of the breakdowns in communication were due to lack of staff (secretarial/clerical) support, resulting at times in a serious misuse of the time of senior personnel to

prepare and transmit information. Additional clerical personnel could also alleviate the signal-to-noise problem mentioned earlier by seeing that information is distributed only where it is needed, and perhaps by labeling information as background, important, actions required, etc.

It was noted that ARC is not presently organized to support projects which cross directorate lines or even division lines within Life Sciences. Similarly, it was suggested that operations would proceed more efficiently if such projects were given the budgetary status. Also, with regard to broad organizational support, it was stressed that while engineering support for SMD III was outstanding, more project engineering resources would be needed for real missions. It was also noted that the human factors aspects of preparing equipment for flight (with regard to effective crew operations) should be given more stress in the organization of future missions. An independent human factors review of equipment and procedures prior to integration and between simulation and flight should be helpful.

Specific issues which were raised included the fact that procedures for dealing with animal health questions were not set out in advance, leading to considerable disruption and confusion during the pre-mission period. A complete plan for backing up all crew members and other critical personnel was not developed and could have led to serious problems had one or more key individuals become incapacitated. Finally, it was suggested that simplification of procedures could have been achieved and the duplication of equipment avoided by more thoughtful integration of experiments early in the project.

In sum, the criticisms and recommendations which were consistently obtained seem more to reflect the difficulties inherent in establishing the management of a new type of operation than any inherent structural deficiencies. In later sections we will discuss the merits of several procedures designed to smooth processes of communication.

Engineers

As we have noted, objective data were not obtained from engineering (Research Support Directorate) personnel. However, interviews with engineers and other project personnel do provide insights into problems encountered and possible solutions. We have mentioned the fact that participants were highly pleased with the quality of engineering support. It was felt, however, that coordination of ARC engineers with PI's and with JSC engineers could have been better and would have been improved by earlier efforts to establish a team relationship. In preparing for flight missions, where engineering demands would be far greater, the need for close and effective working relationships would be critical. The need for an adequate travel budget to establish this coordination is evident.

There was also some feeling that lines of authority between project management and the Research Support Directorate could be improved. In practice, SMD management sometimes worked through Research Support management and sometimes directly with engineering personnel—bypassing their management structure. This practice can lead to misunderstandings, conflict, and inefficiencies in task performance. One approach to this problem would be to place a manager from Research Support in a senior line position to the project. Such a person would not only provide a direct line to engineering staff but also could facilitate liaison with PI's and between engineers at ARC and at JSC.

The broader issue, of course, is the difficulty involved in working across normal organizational lines. Part of the problem can be eliminated by clear indication from senior management that such cooperation is in fulfillment of the overall goals of the organization.

Multiple Commitments and Time Allocation in Projects

We saw earlier how greatly the amount of time devoted to the project varied between classes of individuals and within individuals across time. This stimulates a discussion of the issues revolving around participation in a long-term team effort, such as SMD III or anticipated Spacelab missions. Most senior personnel who have or may become involved in a program such as SMD III are scientists who have ongoing commitments to research or research-related activities. At the same time, a project like this places great demands on the time of participants (as we have noted, much more time than anticipated in many cases). A reasonable question then is whether an individual should plan on devoting full-time to such a project for a period which may be in excess of a year and whether such commitment will harm his professional career.

If SMD III can be taken as even a rough approximation, the answer is a qualified no. Only the ARC personnel with multiple responsibilities (PI/managers) averaged a full-time commitment to the project (actually, it will be recalled, more than full time, 47 hr/week). Of course, in real missions, time demands might be considerably greater. PI's with no other responsibilities showed a rather consistent allocation of about one fourth time while other groups tended to fluctuate from half-time to much more than full-time for shorter, crucial periods such as integrated training and the mission itself. For a substantial number of participants, time appears to be available, although intermittently, to pursue other activities. Dependable planning and scheduling of project activities by management could greatly enhance the usefulness of remaining time.

There are several reasons to encourage scientists involved in such projects to maintain multiple commitments, both to project and nonproject activities. One is based on data obtained from a large study of research scientists by Pelz and Andrews (ref. 14) who found that those with multiple responsibilities were more effective as scientists. Along the same lines, it is likely that the morale (and indirectly, effectiveness) of scientists will be higher if they retain as much as possible of their normal program of activity. Continuing regular activities outside the project may also reduce the risk of losing ground professionally which was voiced as a major concern by several participants.

Given the desirability of participants sustaining several commitments, are there ways of facilitating this and keeping the quality of both normal pursuits and the project high? The answer again must be qualified, but seems to be yes. In the case of PI's, much of the interference with ongoing research stemmed from the disruption of laboratories by the transfer of equipment to the project. PI's were, of all project personnel, least affected by time requirements, but may have lost much research time because of lack of access to needed hardware. The payoff in keeping PI's laboratories intact would seem well worth the expenditure for duplicate hardware (see also the subsection on Principal Investigator-Crew Interface in section VI). Collaboration in research efforts could also assist both project and nonproject research. To the extent that ongoing, nonproject research involves several senior scientists, the diversion of one or more for significant periods to a project would have a less deleterious effect on the operation of a laboratory. Collaborative project research should also ease time demands on individual investigators, although not in any linear fashion.

Adequate staff support (especially in the areas of clerical activities and documentation) should provide some reduction in time demands on project management.

Some consideration should be given to the desirability of designating individuals for extremely time-consuming multiple roles such as PI/manager in a project. Pelz and Andrews (ref. 14) suggest that this kind of multiple commitment may produce the most dedicated and effective organization. However, the demands of the combined roles may be so great as to detract from each role as well as other scientific activities and professional responsibilities.

At the organizational level, much of the success of combining or alternating both basic research and specific projects (such as SMD III) hinges on the acceptance by senior management of this dualistic philosophy of operations. To the extent that management personnel feel that the role commitment of their segment of the organization is to basic, individual research, an individual will be penalized or inadequately supported in a dual role. To the extent that management embraces the dualistic approach, an individual should be able to operate with considerable effectiveness in both settings. It is the responsibility of senior management to guarantee implementation of such support.

A strong trend exists in both fundamental and more applied research toward team, collaborative endeavors. Much of the pressure for collaboration comes from the need to share expensive and scarce hardware and other resources. Other pressures are imposed by the complexities of many research problems which may require investigators with convergent interests and divergent expertise. The limited availability of space and time on facilities such as Spacelab almost demands collaboration. Evidence to date suggests that this approach rather than degrading the quality of science may, indeed, enhance it (see the discussion of patterns of collaboration among Nobel laureates in section VI).

A clear policy should be developed and promulgated by the organization with regard to the approach to research to be embraced. The individual scientist faced with participation in a lengthy project, whether as PI, manager, crew, or some multiple of these roles, should be fully cognizant of the level of support he will receive for his commitment.

Facilitating Communication Within the Organization

The majority of the difficulties encountered in the conduct of SMD III arose from the ambiguities in the specification of goals and responsibilities and from imperfect lines of communication between relevant segments of the organization. Some of these problems will disappear in future projects as the concept of such an undertaking matures, particularly if a cadre of individuals who have gained experience in SMD III occupy significant roles in future endeavors. Other problems are likely to remain. There are no elegant theories of organizations which can provide sure-fire solutions or unflinching panaceas. There are, however, some basic procedures that may prove valuable and which, because of their very simplicity, may tend to be overlooked.

One feature of SMD III was that participants usually tended to act as an aggregate of individuals rather than a team. Notable exceptions occurred when intensive group effort was required to meet project deadlines at various points in the mission. Scattered throughout the interviews are comments about increases in morale and project unity which occurred after occasional social interactions and meetings. Group gatherings, formal designation as a mission team, and public recognition of team

members are very simple techniques to implement, but their effectiveness is proved and they were not fully utilized in SMD III. Public expressions of support and interest by significant members of management are also crucial in sustaining commitment. It is particularly important to establish a feeling of team membership in isolated participants such as university-based PI's and separated coworkers such as those with similar responsibilities at ARC and JSC. Several comments stress the great increase in cooperation and effectiveness which took place among ARC and JSC personnel who had an opportunity to interact face-to-face. The literature of organizations stresses the importance of team feelings in worker satisfaction and their relation to performance (ref. 15) and also their particular importance in demanding, stressful operations (refs. 12, 16). The provision of an adequate travel budget to enable effective face-to-face interactions between personnel, especially among PI's and management and personnel at each Center should be of high priority.

While participants can be assumed to be intrinsically interested and motivated for projects by their professional backgrounds, recognition by senior management of individual contributions to the project and the singling out of individuals for superior achievements can serve both to reassure participants that the activity is valued and to maintain morale. Particularly in a long project with peaks and valleys of demands on participants, expressions of support at milestone intervals can be invaluable.

Because new projects such as SMD III require the definition and implementation of new organizational roles, it is important for management to be sensitive to the kinds of strains that may be imposed on individuals in the organization. The problems involved in creating a new organizational structure include the risk of creating all of the role difficulties discussed in section II. Many of these risks of role difficulties may be reduced or avoided by devoting some time to leadership training for project management. By this we mean formal examination by management of the roles to be filled, possible conflicts between and within roles, and the development of procedures to monitor the effectiveness of role enactment. A series of seminars in which these issues are discussed and their implications evaluated should serve to validate the structure of the project and to increase the responsiveness of management to organizational strains. Argyris (ref. 2) has discussed the employment, by management, of such procedures and advocates their use.

At the beginning of a project and periodically throughout, a series of organizational seminars for participants would be useful in providing channels for the airing of problems, for the establishment of rapport, and for the exchange of ideas. Several respondents emphasized the need for some kind of structured meetings where information could be exchanged between the various elements of the organization. The successful execution of such seminars would require considerable planning to avoid the twin traps of becoming forums for the presentation of management positions or simple gripe sessions. Their potential value should justify such efforts.

Additional procedures for keeping lines of communication open are presented in section VI.

Evaluation of Future Projects

Many of the issues related to the conduct of a major research endeavor such as a Spacelab mission are also relevant to current national trends in the conduct of research, as we have noted.

A research literature is beginning to emerge from investigations of the organization and effectiveness of research teams and the quality of their research (refs. 14, 17).

The number of major studies is still small, however. Thus, it appears that more general benefits could be gained from systematic examination of the conduct of future projects. Basic questions of interest not only for project direction but also for the general administration of science include: management problems in dealing with consortia of researchers; difficulties in establishing and maintaining collaboration; personal characteristics influencing the success of collaboration; competitiveness and cooperation between and within groups; and the relationship of the quality of scientific work to the above factors. The data gained from such research could be unique in providing insights into the structure of complex, coordinated research of all types.

The appropriate time to consider the desirability and scope of project evaluation research would be after the overall structure of a mission has been determined but before research plans and personnel assignments have been made.

VI. FUTURE RESEARCH IN SPACE

In this section we will address broader issues relevant to the conduct of future missions under the constraints imposed by the space environment. These issues range from the philosophy of the research endeavor and the choice of research problems to the management and the integration of the personnel and equipment required. Many of the procedures recommended for consideration grow out of the experiences of SMD III; others are more general in origin and scope.

Selection of Experiments

The choice of particular studies to be conducted on manned spaceflights is a particularly difficult undertaking. A proposal must be evaluated not only on the grounds of individual scientific merit but also as a part of an array of studies competing for limited resources in the form of time, space and hardware. Because of these severe limitations on mission resources, strong motivation exists to select studies which will be "successful" and which can be efficiently integrated into the planned program.

These conditions create a distinct risk that scientific management may lose sight of the primary goal of the research program and select a less than optimum array of experiments. The overriding goal should be, of course, the advancement of science through the discovery of new phenomena and relationships or the rejection of old hypotheses. The pitfall is to define mission success more in terms of the completion of planned studies according to protocol and the acquisition of anticipated data than in terms of scientific advance. If this limited definition is implicitly or explicitly adopted (and the pressures for such a philosophy are considerable), the probability is high that research conducted will consist exclusively of what Kuhn (ref. 18) has called "normal science": the execution of paradigmatic research within the framework of existing theories and methodologies and the avoidance of controversial problems on the frontiers of science. Most of science operates most of

the time under such conditions, but it seems appropriate to question devotion to such an approach in the case of research in space where the number of studies which can be completed is small and the cost per study very high in terms of both money and time for planning and execution. From a cost/benefit point of view, the results of a candidate experiment should be: (1) not precisely predictable in advance; (2) unobtainable by other means (through earth-based research or simulation); and (3) of potential theoretical or applied utility. Put colloquially, if you know how it is going to come out, you shouldn't be doing it as research in space.

Even though a study meets these criteria, its scientific value may be vitiated by other factors associated with the conduct of research in the Spacelab environment. One threat to scientific integrity comes from the process of integrating diverse projects to fit within the physical and operational capabilities of the laboratory and the timeline available during a mission. Through subtle metamorphoses, an experiment may lose much or all of its scientific potential by the time it is integrated into the payload and ready to fly. It is possible that PI's may not notice degradation due to numerous small modifications or that they may be blinded to the effect of changes by their commitment to the concept of a study in space.

A further danger is that rigid protocols for execution may prevent the exploitation of anomalies and theoretically crucial findings. In-flight modification of procedures may lead to significant breakthroughs if data are evaluated and acted upon in real-time. Failing to follow a heuristic approach to the data obtained means that many implications might have to be explored in future missions, a costly and ineffective approach.

Possible resolutions of these problems will be discussed in the following section and in sections dealing with PI's and PI/crew interface, and management.

Given the problem of selecting the best scientific projects but governed by hardware, timeline and integration constraints, a possible approach to evaluation is offered with the realization that many problems can arise from the procedure. Despite this disclaimer, it is felt that a multiphased approach to mission development emphasizing the role of the PI in decision making may maximize the probability of scientific achievement. The proposed system is more time-consuming, complex, and costly than normal evaluation, but appears justified in relation to the cost and importance of orbital missions.

It is suggested that initial proposals be solicited which outline the theoretical importance, general procedures, and hardware required. These proposals would be evaluated both by a peer review committee for scientific merit and by a technical committee for feasibility and problems of integration with other candidate projects. If the solicitation shows that there is an extremely high level of peer review, peer collaboration, and intensive peer cooperation and problem solving throughout the project, this will discourage people from submitting poorly thought out or dishonest proposals. They will see that any lack of integrity will be found out and cause them professional embarrassment with both government administrators and their academic peers. Proposals could be ranked within four broad categories: (1) not scientifically worthwhile; (2) not technically feasible; (3) worthwhile with technical or other modifications; and (4) worthwhile and feasible as proposed. It should then be possible to group proposals by theoretical or methodological similarities and to ascertain overlap between studies. At this point communication with Category 3 and 4 PI's could

take place. In particular, recommendations could be made that investigators sharing theoretical or methodological approaches consider an integrated proposal and that further integration with a NASA PI be explored. It would be appropriate and highly desirable to provide limited funds to PI candidates for such activities.

This recommendation for encouraging collaboration is made in the realization that collaboration may be counter to the research style of many scientists and that collaborative work may tend to seek the lowest common denominator of scientific excellence. It is felt, however, that the nature of research in Spacelab requires a high degree of teamwork and that the development of a team approach may be more effective if the PI's play an active role in the process rather than having such structure imposed after the selection of an experiment for a mission. The advantages of close collaboration between in-house (NASA) and university and other PI's will be discussed later in the section devoted to the role of the PI. It is felt that the scientific integrity of joint proposals can be maintained by having this preliminary integration and modification take place before final peer review for acceptance.

After PI's with proposals in the probable categories have responded to initial feedback and submitted revised and more detailed proposals, final scientific and technical review and acceptance or rejection could take place.

It is also recommended that additional scientific review by peer committee take place after acceptance and before flight simulation to evaluate the effect of integration and later modifications on the scientific worth of the study.

The essence of these recommendations is that scientific review and integration of the battery of experiments proceed hand in hand and that PI's be included in the process during the review and early modification stages. The fostering of communication among potential PI's and between PI's and program management early in planning should also aid in the creation of an effective research-management team.

The Importance of Simulation

The value of the SMD III simulation in developing a management concept and increasing the awareness and effectiveness of PI's has already been discussed. It is our conclusion that simulation of a dedicated mission prior to flight is essential for the success of the research effort. In part, this is because many PI's with important studies will not have had previous experience with this type of enterprise and will need to gain high fidelity experience with the type of long-distance collaboration and direction required. If the research sent into space is to be at the frontiers of science, it is crucial that procedures and communication channels be highly efficient and that a collegial relationship be firmly established between the crew and the ground-based investigator. This type of relationship is crucial if full advantage is to be taken of the implications of obtained data. Along these lines, the simulation can provide vital information on the amount of flexibility which should be built into timelines to allow for capitalizing on serendipitous findings.

SMD III was a development mission, not a preflight simulation. As such, the experimental hardware and timelines were designed around Earth-ideal rather than zero-g constraints and were

designed to stress the crew and support personnel and systems. For preflight simulations of Spacelab missions, however, great care should be taken to develop timelines based not on Earth-ideal working conditions, but on zero-g working conditions. These timelines should be based on the best estimates of persons who have objective knowledge of the problems of working in zero-g.

Essential to the success of a mission is awareness on the part of the PI, crew, and management that the simulation is not just a debugging of fixed procedures but rather the pilot research and development of an approach to unique scientific problems. Participants in a simulation learn the personalities of other project members and the most effective methods of working with them. If particular individuals are incapable of coping with particular roles or working in certain groups, personnel shifts can be accomplished without total disruption of the project. In essence, problems are faced while they are still correctable.

In the course of simulation, scientists who have not operated under these conditions should become motivated to rehearse the effects of equipment or procedural failures and to develop decision strategies for coping with them. Under the conditions of simulation (where there are time, resources, and the calmness needed to evaluate solutions dispassionately), much better procedures can be developed than would be possible during a real emergency if personnel had no prior experience in dealing with perturbations, real or imposed, during simulations.

The Role of the Principal Investigator

In dedicated science missions, the central role is that of the principal investigator, whose research justifies the entire project. An understandable tendency is to recognize the importance of the PI in developing the experiment and in analyzing and presenting the results but to overlook his role during the integration and execution of the research. If the concept of a space laboratory is to be fulfilled, consultation and direct collaboration of the PI during the conduct of the experiment must be defined in the project plan (see further discussion of this issue in the PI-crew subsection below).

It is possible that some PI's, especially those from outside NASA, may be unaware or only partially aware of some of the demands and constraints imposed by the space environment. It seems important to make these factors explicit and to ensure that PI's recognize them before committing themselves to an experiment.

One element is the amount of time required for an experiment run under space conditions. Training, integration, and execution require a far larger investment of PI time than research of comparable complexity in earthbound laboratories. It was a recurrent theme in interviews with SMD III PI's that the extent of this time commitment was grossly underestimated. (We have noted that the actual time demands on PI's were not high, but disruption due to equipment loss was often great.) Any scientist considering participation should have a realistic appraisal of the effect of an experiment on his other activities, particularly the need to be physically present at an operation center during simulation and flight. Related to this was the opinion voiced by some PI's that commitment to a flight experiment could result in losing ground in one's profession due to the inability to keep abreast of current developments. It was felt that this could be a particularly serious problem for PI's with university commitments.

A portion of the problem associated with time demands may be alleviated by the collaboration of PI's on a joint experiment encompassing several individual interests. Some aspects of the paperwork, training, and integration problems may be spread out among the several participants. It may prove beneficial, especially for PI's unfamiliar with the structure and operation of NASA to collaborate with a scientist from NASA. Critical tasks associated with major collaboration include the establishment of high levels of mutual trust and respect and insuring that no aspect of the study is neglected or overlooked through the diffusion of responsibility. These are not insurmountable hurdles, however, and are probably outweighed by the benefits to be gained from a team approach to particular studies.

The beliefs that scientists, especially great ones, are loners and that major scientific contributions tend to be the product of individual creativity are widespread (for example, see refs. 19, 20). A recent study of scientific elites, however, Zuckerman (ref. 17) gives strong evidence against these beliefs. Overall, for example, 65% of Nobel prizes in science have been awarded for research which was unambiguously collaborative. Longitudinal data on the patterns of collaboration by laureates clearly document the shift toward a team approach in groundbreaking research. From 1901 to 1925, 41% of the science awards were for collaborative research; during the second 25 years, the increase was to 65%. Currently, 79% of science laureates are honored for collaborative work. Using this standard of comparison, the argument that research quality must inevitably suffer from collaboration is unsupportable.

Problems associated with the development of a collaborative approach have been mentioned. These are particularly salient vis-a-vis relationships with crew members who will actually carry out the research. There are two possible roles for a crew member: one is to serve as a technician, limited to carrying out the detailed protocol established by PI's; the other is to serve as an extension and collaborator of the PI, carrying out the research as a partner in the enterprise. The latter is closer to the spirit of a laboratory in space and is more likely to result in a creative piece of research.

Given this approach, the PI needs to be able to establish a close working relationship with the crew and to feel that the research is indeed a common effort. This suggests a period of working together in the PI's laboratory and a thorough explication of the theoretical and methodological rationale for the experiment.

The PI must also be able to interpret and act upon data with rapidity. If any procedural changes are to be introduced and new data obtained during a mission, plans must be developed with the crew and executed within a very limited time. Unlike most normal research, the opportunity for lengthy reflection and replication is not present.

The Role of the Crew

As noted above, to maximize the research potential of a mission, crew members should serve as scientists in space rather than as skilled technicians. To fill this role as a scientist places a considerable burden on the crew member. This is compounded by the fact that the pre-mission time demands on the crew will certainly be very high. Thus the risk of becoming professionally obsolescent is probably greater for the crew than for individual PI's involved in the program. (The problem is similar although less severe than that faced by earlier science astronauts; for example, ref. 21.)

It is assumed that individuals choosing to volunteer for the crew role will be aware of the potential professional loss and will have based their decision to participate on other personal and professional benefits from the program. Nevertheless, the diversion from professional activities is likely to be a source of concern to most crew members.

The process of integrating the crew member with the PI to fill as close to a full collaborator's role as possible may serve related purposes beyond enhancing the scientific value of the research. One is to increase the involvement and motivation of the crew member as surrogate experimenter. No one can question the desire of past space crews to give maximum effort on all assigned tasks; however, the literature of motivational psychology provides ample evidence that deep personal involvement can even improve the performance of highly motivated individuals. The process of deeper commitment to scientific experiments may also serve to broaden the scientific expertise of the crew member and to keep him abreast of frontiers in areas with at least some relevance to his own specialty.

Principal Investigator-Crew Interface

As the foregoing has suggested, maximizing interactions between PI and crew before and during missions is seen as a major component of the conduct of successful science in the space environment. Beginning with the early planning of a mission, it would seem highly desirable for both PI's and crew members to play a joint role in the assignment of the crew to conduct particular experiments. An example of lack of consideration of this problem is the fact that one back-up crew member who was also a PI was not assigned to that experiment. The probability of a successful collaboration would be considerably enhanced if the selection were mutual rather than imposed by management from outside. Obviously, the constraints of timelines and integration may not allow for optimal pairings in every case, but attempts to conform to this procedure as much as possible should be beneficial.

We have previously noted that it appears useful to have hardware in the PI's laboratory that duplicates hardware that will fly. This can enhance crew work in the PI's laboratory and can reduce the negative effect on training and the PI's research while the equipment is being integrated into Spacelab.

The physical presence of the PI at a communication center during simulation and flight is imperative. Only with the PI present can decisions based on data or unanticipated problems be made rapidly and effectively. The presence of PI's may also serve as a subtle but significant motivating factor for the crew. If, however, maximum benefit from the PI's presence is to be gained, there should be few restrictions on communications between the crew and PI during simulation and flight. We have noted the need for such communication in innovative and collaborative research. Using communicators to pass information back and forth can destroy the effectiveness established by earlier collaboration. As previously suggested, the provision of a teletype device in Spacelab to allow hard copy messages to be passed to the crew would be highly useful. Ideally, in addition to the telex channel, a voice channel for each payload crew member should be provided with provision for control at the discretion of the crew member who may need isolation during certain evolutions.

The Role of Management

The primary role of management on a dedicated science mission should be to facilitate the safe and effective conduct of the highest quality research, remembering that success is measured in terms of the quality of the scientific output, not the number of studies completed. In this section a series of recommendations will be made to attempt to facilitate the attainment of this goal.

1. Provide prospective principal investigators with a handbook which details operational and organizational characteristics of the mission. This should include:

- a. An explicit statement of research goals and philosophy
- b. Space and hardware limitations of Spacelab
- c. Guidelines as to time available for experiments (this, of course, cannot be estimated precisely until the array of experiments is integrated)
- d. Realistic estimates of the time demands on PI's for design, training, integration, simulation and flight
- e. A statement of the organization of the project, including the relationship of the crew and PI's to management and the role of PI's in decisionmaking regarding the integration and execution of the experiment
- f. Delineation of the role of the crew member vis-a-vis the PI in training and the conduct of the experiment, including specification of in-flight communication procedures and limitations

It is felt that a number of problems can be avoided or minimized if prospective PI's embark on projects with a realistic expectation of the kind of team enterprise they will encounter and awareness that their autonomy as investigators must, of necessity, be less than in normal research.

2. Establish a clear line of authority with regard to decisions concerning all aspects of the scientific mission. PI's and the crew should be clearly aware of the final authority for the establishment and modification of procedures which directly or indirectly influence experiment protocols or data.

The lines of authority within the project should reflect the demands of the mission rather than the position of individuals in the larger organization. Thus, when project constraints dictate, non-PhD holding individuals may be directing the activities of senior PhD scientists. If the organization clearly defines these relationships, potential problems from this reversal of usual status relationships can be minimized.

The need for a clear and effective decision making hierarchy with provisions for input from all segments of the program may be particularly great if budgetary or operational conflicts necessitate changes or reductions in planned research during mission development. Such situations, if not handled sensitively and with maximum input from concerned individuals, are most likely to result in serious interpersonal conflict and to lead to the unintended degradation of the scientific effort.

3. Vest final control for the scientific mission in a science manager with authority over mission and payload specialists. This individual would have final decision making power over all aspects of integration and in-flight procedures (excluding flight operations and safety-related aspects of the flight) and would resolve appeals from both PI's and the crew with regard to the modification and integration of experiments and timelines.

4. Maintain a scientific peer review committee to evaluate the scientific merit of experiments throughout the process of integration and training. This body would advise and assist the science manager in maintaining the integrity of the research from inception to execution and would be of particular value in the case of disagreements between PI's and management regarding the effect of integration on the effectiveness of experiments.

5. Establish a management position of science liaison manager. The role of this individual would be to serve as a link between PI's and management. One function would be to visit PI's in their laboratories to discuss progress and to determine if any problems which might impact the mission are developing. The science liaison manager would also serve as a contact point for PI's with management and engineers in charge of integration for all matters related to the experiment. The role function is seen primarily as communicator rather than decision maker. Presumably both management and PI's would see this person as an advocate in presenting positions to the other party.

6. Include PI's and the crew to the maximum possible extent in the decisionmaking process regarding the integration of experiments, scheduling, and training. A frequent complaint in SMD III was that PI's were not aware of many decisions which affected their experiments or personal schedules. The science liaison manager could plan an important role in this area in making sure that PI's are aware of problems and questions regarding their experiments and in making management cognizant of PI problems which might require management attention.

Conclusion

The experience of SMD III suggests that an effective management structure has evolved which can integrate and conduct complex research within the constraints of a zero-g laboratory. The recommendations made here recognize this achievement and are made in the interests of developing an organization with open communication channels, motivated participants, and a sufficiently clear organizational structure to reduce conflicts between the goals of individual participants. At the same time, the proposed organization and procedures are intended to provide enough flexibility to recognize the indirect course of scientific discovery and the importance of giving all involved individuals a voice in decisions influencing their roles and responsibilities.

The greatest risk in a case study such as this is that persons who were directly or indirectly involved or who anticipate involvement in future projects may acknowledge or even agree with the relevance of points raised but may fail to examine critically their own actions and roles with regard to these issues. Argyris and his colleagues (refs. 2, 22) have discussed the problem of personal role examination extensively. They recommend that individuals indulge in a careful diagnosis of their actions and assumptions in critical situations, test the validity of these assumptions about the causes of particular outcomes, and accept the fact of *personal* causation for important events. Using this approach, individuals may acquire an openness to organizational change and a sensitivity to the causes and nature of the reactions of others.

If this report stimulates readers to evaluate carefully their own roles in organizations, whatever their decisions concerning proposed procedures, it will have served its function.

VII. EPILOGUE

A management study was initiated by Ames Research Center (ARC) to document Spacelab Management Development Test III (SMD III) activities and problems. The purpose of the study was to provide conclusions and recommendations to project management for current and future managers of ARC life sciences projects. This brief summary of the study includes a set of recommendations which are derived directly from that study. The recommendations presented here are relevant to life sciences as well as other scientific participation in future space missions.

Introduction

SMD III was the third in a series of ground-based simulation experiments designed to test logistics and management procedures for life sciences space experiments. SMD III differed from earlier simulations in that it was a dedicated life sciences mission; that is, most of the experiments on board dealt with humans or animals. All three simulations were conducted at Lyndon B. Johnson Space Center (JSC), Houston, Texas. However, since most of the life science support is at Ames Research Center (ARC), Moffett Field, California, it was decided to make SMD III a collaborative effort of JSC-ARC. ARC responsibilities were: to propose human and animal experiments for inclusion in the test; to develop the hardware for the experiment and integrate it into the experiment racks; to deliver the payload of equipment to JSC; to develop documentation procedures for life sciences experiments; to conduct crew training for the ARC experiments; and to provide crew and management personnel as necessary for the successful completion of the project.

ARC experiment proposals were solicited 9 April 1976, and final selections were made after an initial review of each proposal by a joint JSR-ARC committee. The crew was selected and began training, first in the laboratories of the individual principal investigators (PI's), then at ARC with all ARC experiments in the Spacelab configuration. The integrated equipment was shipped to JSC on 14 February; it was reassembled and double-checked in the simulator. The crew then trained individually with all experiments in the final Spacelab configuration. Final training was a preliminary run of 2 days of the actual 7-day simulation. The 7-day simulation began 17 May, only 2 days later than originally scheduled. The test was successful: it did not fall seriously behind schedule, and all experiments but one produced usable data. ARC fulfilled its responsibilities for staff, experiments, and hardware, and ARC and JSC collaborated successfully in bringing about the simulation.

Another goal of SMD III was to set up and test the operational problems which would be associated with a Science Operations Remote Center (SORC). Since most PI's were at ARC, and the

simulation was conducted at JSC, a SORC was set up at ARC which received data from the simulator in Houston for review by individual PI's. The SORC concept operated well once the data link was established and there were few data handling problems during the simulation.

The reader is referred to the following sources for more detailed descriptions of the project and recommendations for future Spacelab missions.

1. The SMD III Science Management Report, coordinated by John A. Rummell and Paul X. Callahan. February, 1978.
2. Spacelab Mission Development III Test Operations Report, Glen H. Cress III, August 29, 1977. This report was originated from the JSC side of the project and refers the readers to other JSC reports on SMD III.
3. Two articles referring to SMD III appeared in *Aviation Week and Space Technology*, 9 May and 27 June, 1977.
4. A handbook for managers of future projects such as SMD III is being prepared by the authors. It is based largely on the results of the SMD III Management Study.

Major Issues and Recommendations

Effect on other ARC activities—The effect on other ARC activities was considerable in terms of diversion of funds, equipment, and manpower from usual scientific research. Initially, reactions from participants were lukewarm and often resistant; however, later in the project participants began to realize that demonstrating Ames' capability was as important as the usual task of producing publishable scientific data. It is recommended that steps be taken to ensure that everyone knows priorities from the start:

1. Explicit information should be provided to all project personnel on center *and* directorate goals and long-term priorities at the start of the project.
2. Participants should receive assurance that their normal job will not be jeopardized if they choose to participate in the project.
3. Realistic estimates should be provided of time and travel requirements for project participants, based on SMD III experience.

ARC and JSC collaboration—Collaboration between ARC and JSC was generally excellent. The problems which did arise suggest that:

1. As early as possible, the Center responsible for initiating the project should set up an information center to aid project participants in getting current information on earlier

simulations, mission guidelines, equipment integration requirements, documentation procedures, and the status of various aspects of the project. Such an office should be accessible to all project personnel and would greatly aid in intercenter communications.

2. For better engineering coordination, early efforts should be made to establish a team relationship between the engineers at one Center and engineers at the other, and between individual PI's and the engineer responsible for their equipment.
3. If one Center is responsible for delivering the animal payload to the other, it should review the animal health and maintenance procedures of the recipient Center in order to reduce concerns of one Center with the procedures of the other.

The Science Operations Remote Center (SORC)—SORC was usefully employed for real-time data presentations to the PI's and as a communications center for relaying messages between the crew and PI's via the JSC Payload Operations Control Center (POCC). In an actual life sciences mission, the SORC could also have been used as a laboratory in which to monitor ground-based control groups for the airborne experiments and for yoked air-ground studies for which PI's must be present. Experience in the SORC led to the following suggestions:

1. A cost-effectiveness evaluation of SORC(ARC)-POCC(JSC) vs POCC-SORC(JSC) should be conducted.
2. A clearer and more liberal policy for POCC-SORC and SORC-Crew communications should be defined to enhance the value of the SORC in terms of scientific productivity.
3. SORC Management should have access to all POCC communications. A video link between POCC and SORC would be helpful.
4. As few restrictions as possible should be placed on PI-Crew communications. Provide a separate voice channel for each crew member.
5. A hard copy printer should be provided as an additional means of communications to the crew. This is especially helpful for numeric or engineering information.
6. Full video coverage should be provided to SORC, rather than slow scan.

Principal investigators—In dedicated science missions, the central role will be that of the principal investigator, whose research justifies the entire project. The majority of PI's felt SMD III was an important learning experience in the conduct of project research. They expressed a number of concerns which lead to the following suggestions:

1. PI's (especially non-NASA PI's) must be made aware of realistic time requirements, autonomy constraints, and procedural requirements so they can appraise the effect of running a space flight experiment on their time and with their resources before committing themselves to such a project.

2. An experienced NASA scientist should serve with outside PI's as an experiment team coordinator and liaison between NASA project management and the PI.
3. PI's and their liaisons should be consistently informed by management, especially about any modifications in procedures which may influence the conduct of their experiments.
4. Duplicate sets of flight experiment equipment should be made available to facilitate crew training and the ongoing research of PI's.
5. As early as possible, a handbook should be provided to PI's specifying the organizational and operational characteristics and limitations of the mission. It should include:
 - a. An explicit statement of research goals and philosophy
 - b. Space and hardware limitations of Spacelab
 - c. Guidelines as to time available for experiments (more precisely estimated once experiments are integrated)
 - d. Realistic estimates of the time demands on PI's for design, training, integration, simulation, and flight monitoring
 - e. A statement of the organization of the project, including the relationship of crew and PI's to management and the role of PI's in decisionmaking regarding the integration and execution of the experiment
 - f. Delineation of the role of the crew member vis-a-vis the PI in training and in the conduct of the experiment, including specifications of in-flight communication procedures and limitations
6. The flow of paperwork should be restricted so that only relevant information is sent and only to appropriate persons.
7. Clear lines of authority should be defined for decisionmaking about experiments.
8. To ensure the best quality of science, early collaboration should be encouraged between crew, PI's, and their liaisons on the assignment of the crew to specific experiments, procedures development, and crew training. Extensive communication among these individuals should be allowed and encouraged during the conduct of the experiment.

Crew—The precise status of crew members vis-a-vis PI's and with regard to their role in the execution of experiments was not clearly defined in SMD III. There are two possible roles for a crew member: (1) technician, limited to carry out the detailed instructions established by PI's, or (2) an extension and collaborator of the PI's carrying out the research as a partner in the enterprise. We tend to support the view of crew member as scientist in space, but in any case, management should:

1. Define the extent of crew autonomy in actual execution of the studies, data collection, and consultation during flight.
2. Make explicit at the outset the lines of authority and communication between the crew and science management and the crew and PI's (e.g., who is responsible for evaluating the adequacy of preparations for particular experiments?).
3. Define explicitly the role of back-up crew and the extent of their commitments for training.

Management—The primary role of management on a dedicated life science mission should be to facilitate the safe and effective conduct of the highest quality research. The management structure for SMD III was similar to that used for previous simulations except that it was linked through the Mission Management Board to JSC. An effective management team developed during the course of the project. Comments aimed at improving a satisfactory performance are:

1. The management skills developed during SMD III should be tapped for future life sciences projects.
2. Consistent communications should be created between management and PI's, keeping PI's informed on decisions concerning their experiments, and keeping management informed on progress of PI's.
3. More clerical support should be provided to managers to prepare and distribute information, sending it only where needed and perhaps labeling its importance (action required, background, etc.).
4. Procedures should be worked out before the project begins for funding and executing projects that cross directorate or division lines.
5. There should be independent human-factors review of equipment and procedures prior to integration and again between integration, simulation, and flight.
6. A complete plan should be developed for backing up all crew members and other critical personnel.
7. Managers should be free of other role commitments in the project. For example, managers who are also PI's probably do not have the time and objectivity to manage optimally.
8. The relationship between mission specialists and payload specialists should be delineated, vesting final authority in a science manager.
9. The establishment of a science liaison manager to serve as a communication link between all PI's or subsets of PI's and management should be considered.

Engineers—Overall, participants were highly pleased with the quality of engineering support. Suggestions for improvement include:

1. Lines of authority should be improved between project management and research support directorate (RSD). A manager for RSD in a senior line position on the project through whom all engineering requests could be channeled would provide the necessary coordination.
2. A clear indication should be provided to engineers from senior management that cooperation across normal organizational lines is in fulfillment of the overall goals of the organization.

Multiple commitments and time allocation in projects—Nonmanager scientists involved in such projects as SMD III could maintain multiple commitments, both to project and nonproject activities. For a substantial number of participants, time appears to be available, although intermittently, to pursue other activities. The following suggestions are aimed at facilitating this:

1. The project manager should plan and schedule project activities as dependably as possible to enhance the usefulness of remaining time.
2. The project manager should encourage collaboration in research efforts. This would ease time demands on individual investigators and allow laboratory operation to continue more smoothly.
3. Directorate management can facilitate the success of combining or alternating basic research and specific projects by supporting individual scientists in dual roles. A clear policy should be developed and promulgated.

Facilitating communication within the organization—Many problems will disappear as the project concept matures, particularly if individuals experienced in SMD III occupy significant roles in future projects. The majority of the difficulties encountered in the conduct of SMD III arose from ambiguities in the specification of goals and responsibilities and from imperfect lines of communication between relevant segments of the organization. These problems have been addressed throughout this report, but some other simple basic procedures may prove valuable:

1. Project commitment and a feeling of team membership should be established by group gatherings (social interactions and meetings) and early public recognition of team members' contributions, especially by upper management.
2. To help establish feelings of team membership in isolated participants such as university PI's and separated coworkers such as those with similar responsibilities at ARC and JSC, NASA should provide an adequate travel budget for face-to-face interactions.
3. A series of leadership training seminars should be provided by NASA for project management to discuss the roles to be filled, possible conflicts between roles, and procedures to monitor the effectiveness of role enactment.
4. A series of regular organizational meetings should be established for participants and management to air problems, establish rapport, and exchange ideas. (Make the effort to avoid one-way position presentations and simple gripe sessions.)

5. After the overall structure of a mission has been determined but before research plans and personnel assignments have been made, these plans should be reviewed by an independent project evaluation committee.

Future Research in Space

This section addresses issues relevant to the selection and development of scientific experiments that are to be executed in space. The problems of selecting significant scientific proposals and developing these into an efficiently integrated payload often lead to compromises in both the quality of the science and the efficiency of the payload integration. We recommend guidelines, for selecting and developing studies, which emphasize the role of the PI in the decisionmaking, and the importance of early team work in payload integration:

Selection and integration of experiments—Avoid the pitfall of selecting experiments because they can be efficiently integrated and because their success is predictable. The results of a candidate experiment should be:

1. Not precisely predictable in advance.
2. Unobtainable by other means (Earth-based research or simulation).
3. Of potential theoretical or applied utility.

A multistage decisionmaking procedure is recommended for selecting scientifically sound experiments and integrating them so that an efficient payload is developed:

1. Initial proposals should be solicited which outline the theoretical importance, general procedures, and hardware required.
2. Scientific peer review should be employed to evaluate the scientific merit of each proposal. In addition, a NASA engineering committee should be employed to determine the feasibility of translating the set of research proposals deemed meritorious into an integrated, efficient, on-board set of experiments.
3. Proposals should be categorized as: (1) not scientifically worthwhile, (2) not technically feasible, (3) worthwhile and feasible with technical or other modifications, and (4) worthwhile and feasible as proposed.
4. It should then be possible to group proposals by theoretical or methodological similarities to ascertain overlap between studies. At this point communication with proposal category 3 and 4 PI's could take place. Recommendations could be made (and limited funds provided) that PI's sharing approaches consider an integrated proposal and that further collaboration with a NASA PI be explored.
5. Final proposals (revised, combined, more detailed) should be accepted or rejected by further scientific and technical review.

6. The effect of integration and later modifications on scientific worth should be evaluated with an additional peer review before final integration to ensure that scientific value is not lost due to “minor” modifications deemed necessary to make it fit into mission timelines and Spacelab characteristics.

In essence: Maintain scientific excellence and create an effective PI-PI and PI-management team by having scientific review and integration of experiments proceed hand-in-hand and by including PI's early in the process. Additionally:

1. For zero-g experiments, great care should be taken to develop timelines based *not* on Earth-ideal working conditions, but on zero-g working conditions. These timelines should be based on the best estimates of persons who have objective knowledge of the problems of working in zero-g.
2. Data should be evaluated as they are being collected. The PI should be prepared to pursue further any unanticipated findings by allowing some flexibility in experimental procedures and timelines.

The importance of simulation—The value of the SMD III simulation in developing a management team and increasing the awareness and effectiveness of PI's in research projects has been discussed previously.

Simulation of a dedicated science mission prior to flight is essential for the success of the research effort. The rationale is that in a simulation the PI's gain experience with long-distance collaboration and direction. All participants develop efficient procedures and communication channels and establish collegial relationships with the crew. Management can determine the amount of flexibility needed to capitalize on serendipitous findings. All parties can rehearse or experience the effects of equipment or procedural failures and can develop decision strategies for coping with them or for eliminating them before they can recur. Problems are still correctable, such as learning the most effective methods of working with individual project members and adjusting roles or working groups as needed.

In conclusion, the experience of SMD III suggests that an effective management team, selected from the personnel of a research facility, can successfully direct complex life science research within the constraints of a zero-g laboratory.

Ames Research Center

National Aeronautics and Space Administration

Moffett Field, California 94035, June 10, 1978

APPENDIX A

MEMORANDUM INITIATING AMES RESEARCH CENTER PARTICIPATION IN SMD III

NASA-AMES L:200-7
Moffett Field, California
April 9, 1976

MEMORANDUM for Trieve Tanner, Life Sciences Directorate.

From: Joseph C. Sharp, Deputy Director of Life Sciences

Subject: SMS II Briefing and ARC Participation in SMS III

We have arranged for Messrs. Bush, Musgrave and Shumate to provide us with an in depth briefing on SMS II which was recently completed at Johnson Space Center. This briefing is to be held on April 22 commencing at 8:30 a.m. in the Space Sciences Auditorium which is located in Building 245. It is intended to provide each of you with the necessary background information so that we can actively participate in SMS III. It is patently obvious that to survive through the Shuttle era we must develop the capability of doing good science in the Spacelab and be able to provide the necessary "services" to all principal investigators who will be doing biological life science research. The SMS III is for the Life Sciences dedicated Spacelab and not for SL-1 or SL-2. The service function will include the design of, training for, integration of, and payload management of the experiments that will be conducted in space.

In order to insure that we overcome the understandably reserved attitude many of our people have regarding Ames Research Center's participation in supporting and conducting life science experiments in Spacelab, I am requesting that every principal investigator attend this SMS II briefing. By no later than May 5 you are expected to have in my office a proposed "experiment" that could be used in SMS III. Propose only those "experiments" that you can do without extensive new methods development or equipment design. Remember, the Spacelab simulator will have scientists aboard to do the manipulations. In fact, you may be one of the people selected to go aboard as a payload specialist. (Attached is the format to be used for preparation of the proposed "experiments." Please follow it carefully.) We will hold a quasi-formal selection procedure on May 10 using techniques similar to those we anticipate will be used later in selecting actual flight experiments.

The resources - fiscal, personnel, and space - of the entire Directorate will be used to assure the successful completion of this exercise. This simulation exercise may entail some personal inconveniences, including temporary reassignment, curtailment of leave, some travel restrictions, and/or additional travel to Johnson Space Center.

L:200-7 - April 9, 1976

2.

We have obtained an agreement from Dr. David L. Winter that the work of affected tasks can either be suspended for the duration of the SMS III tests or redirected to accomplish the goals of the simulation.

I expect each of you to attend the Johnson Space Center briefing, to submit a "doable" project and, as projects are selected, to participate fully in the SMS III. You may wish to contact those who are under contract or who have grants with us and ask them if they would like to actively participate. Supplementary funds to the grantees and/or contractors will not be available for this exercise. But notice, for example, all of those who checked the flight experiment box on the T-41 should have no difficulty in preparing a proposed "experiment." You now have an opportunity to take the first tentative steps in getting your program on a future flight. If we can develop the necessary skills and techniques to successfully complete the SMS III, I am reasonably sure we can obtain and discharge the responsibility for planning an active role in the future. If we are not successful the future will, indeed, be bleak.



Joseph C. Sharp

Enclosure:
Format

Note: This memorandum is representative of those sent to selected personnel in Life Sciences initiating the project.

APPENDIX B

MEMORANDUM INITIATING SMD III MANAGEMENT STUDY

NASA-AMES LB:236-5
Moffett Field, California
October 28, 1976

MEMORANDUM for Distribution

From: William E. Berry, SMD III Project Manager
Subject: SMD III Project Management Study

Procedures for documenting our participation in SMD III are being expanded. The objective in establishing a formal documentation procedure was to develop a clear picture of significant day-to-day Project activities, so that in the future we could repeat those things we have done correctly and correct any mistakes we have made.

The original plan of having members of the Project team supply Mark Patton with all records of activities relevant to the Project has not yielded as much information as expected. The material that has been obtained, primarily copies of official memoranda, is valuable, and its collection will be continued. However, since this material in itself does not seem to fulfill the objective, a more active collection procedure is being initiated. Trieve Tanner will take primary responsibility for this part of the program. Dr. Tanner, or one of his assistants, will visit you on a fairly regular schedule (once every week or two) throughout the remaining duration of the Project to obtain the desired information.

The visits will be brief and will involve only a few short questions regarding your participation in the Project since the last visit. The questions will be concerned with time allocation to the Project, scheduling, any problems that may have arisen involving hardware, training, etc. The initial visit may require more time than the others, since an attempt will be made to account for the more significant activities that have occurred since the start of the Project.

Some of you may recognize that the documentation activity overlaps with Dr. Tanner's research interests in developing behavioral observation and training techniques for improving human performance and behavior in space. It should be emphasized that, while information obtained from the documentation exercise may benefit his research program, his participation is primarily for the benefit of the Project.

I recognize that most of you are already devoting considerable amounts of time to the Project. With your other commitments in mind, Dr. Tanner and I have agreed that the documentation exercise should be as non-intrusive as possible. Your cooperation in the exercise will contribute greatly to the development of an effective set of procedures for future participation in similar projects.


William E. Berry

Distribution:

Code L

All SMD III Principal Investigators

SMD III Project Office

APPENDIX C
SMD-PROJECT MANAGEMENT SURVEY

Name:

Week of:

How much time did you spend on SMD during the past week? hrs. total

Was there any discrepancy between time planned and time spent? yes no

If yes, indicate the cause and amount of discrepancy

How was your time allocated? (Consider these categories mutually exclusive)

- | | |
|--|------|
| A. Paperwork and general administrative meetings | Hrs. |
| B. Program modification | Hrs. |
| C. Equipment design/redesign | Hrs. |
| D. Clarification | Hrs. |
| E. Training | Hrs. |
| F. Other (please specify) | Hrs. |
| | Hrs. |
| Total (should equal the total hours, above) | Hrs. |

What problems have arisen during the week? (Please check all applicable categories; do not consider these mutually exclusive)

- | | |
|--|--------------------------|
| 1. Personnel | 7. Equipment integration |
| 2. Equipment redesign | 8. Time lines |
| 3. Crew training | 9. Interface with JSC |
| 4. Getting needed information | 10. Paperwork |
| 5. Interface with other SMD experiments | 11. (other, specify) |
| 6. Interference of SMD with other (non-SMD) activities | |

Give any comments you care to give concerning problems encountered, or other aspects of SMD

Please list persons with whom you have had most important interactions during the past week regarding SMD

Use the back of this sheet if you need more space to complete any of the above items.

SMD Project Management Survey—Final Questionnaire

1. What is your evaluation of the overall success of SMD-III in terms of:

A) your own role? (circle appropriate point on scale)
1-----2-----3-----4-----5
not at all very

B) ARC?
1-----2-----3-----4-----5
not at all very

C) NASA?
1-----2-----3-----4-----5
not at all very

2. How valuable was the exercise for:

A) you?
1-----2-----3-----4-----5
not at all very

B) ARC?
1-----2-----3-----4-----5
not at all very

C) NASA?
1-----2-----3-----4-----5
not at all very

3. How useful would be another simulation (or Development) of the first dedicated life science Spacelab Mission?

1-----2-----3-----4-----5
not at all very

4. If Ames is involved in another simulation, how interested would you be in participating?

1-----2-----3-----4-----5
not at all very

5. If you were involved in another simulation or a flight, what role(s) would you prefer to fill? (circle one or more):

- 1. Crew
- 2. PI
- 3. Manager
- 4. Engineer

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| 16. Abstract <p>Spacelab Mission Development Test III (SMD III) was the third in a series of ground-based studies designed to test logistics and management procedures for future life sciences space experiments, particularly Spacelab. This study was the first collaborative effort of two NASA centers, Lyndon B. Johnson Space Center (JSC) and Ames Research Center (ARC). ARC responsibilities were to propose, develop, integrate, and deliver a payload of life sciences experiments to JSC where a 7-day simulation was conducted. ARC developed documentation procedures, trained the crew on the experiments, and provided crew and management personnel as necessary for the successful completion of the project.</p> <p>A management study was initiated by ARC to specify SMD III activities and problems. This report documents the problems encountered and provides conclusions and recommendations to project management for current and future ARC life sciences projects. An executive summary of the conclusions and recommendations is provided. The report also addresses broader issues relevant to the conduct of future scientific missions under the constraints imposed by the space environment. Many of the procedures recommended for consideration in the last section grow out of the experiences of SMD III; others are more general in scope and origin.</p> | | | |
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